Western and Central Pacific Fisheries Commission

Pacific Community
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PROJECT
Sustainable Management of Tuna Fisheries and Biodiversity Conservation in the ABNJ

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REDUCING ECOSYSTEM IMPACTS OF TUNA FISHING

Joint Analysis of Sea Turtle Mitigation Effectiveness

FINAL REPORT

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HONOLULU, HAWAII, USA

COMMON OCEANS

PROCEEDINGS

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Seeking to generate a catalytic change, the *Global sustainable fisheries management and biodiversity conservation in the Areas Beyond National Jurisdiction Program* was approved by the Global Environment Facility (GEF) under the lead of the Food and Agriculture Organization of the United Nations (FAO) in close collaboration with two other GEF agencies, the United Nations Environment Programme (UNEP) and the World Bank, as well as other partners.

Focusing on tuna and deep-sea fisheries, in parallel with the conservation of biodiversity, the ABNJ Program aims to promote efficient and sustainable management of fisheries resources and biodiversity conservation in ABNJ to achieve the global targets agreed in international fora.

The five-year ABNJ Program is an innovative, unique and comprehensive initiative working with a variety of partners. It consists of four projects that bring together governments, regional management bodies, civil society, the private sector, academia and industry to work towards ensuring the sustainable use and conservation of ABNJ biodiversity and ecosystem services.

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Executive Summary

Introduction

In response to the problem of unwanted bycatch, tuna fisheries have adopted a number of measures to mitigate threats to bycatch species. However, in many cases the degree to which interactions and mortalities are expected to be reduced as a result of these measures, and are actually reduced, remains unknown. This is at least partially because studies of the effectiveness of mitigation options often lack statistical power due to small sample sizes and/or represent only a small subset of fishing operations. To overcome these shortcomings, integrated analysis of combined datasets representing different fisheries, locations, and operational variables can be used to assess the effectiveness of various mitigation strategies.

Although sea turtles interact with both purse seine and longline fisheries, a recent ecological risk assessment conducted for the Atlantic suggested that overall mortality from purse seine fisheries is inconsequential compared to longline fisheries (Angel et al. 2014)[1]. This is likely due to the fact that as predators sea turtles are attracted to baited hooks, and there is a higher chance of asphyxiation in longline fisheries particularly when turtles become hooked and can't reach the surface to breathe. The only tuna RFMO to adopt a conservation and management measure (CMM) that requires specific changes in fishing practices (i.e. beyond safe release) is the Western and Central Pacific Fisheries Commission (Clarke et al. 2014). The WCPFC's CMM (2008-03) applies to fleets fishing in a shallow-set manner for swordfish, and each member or cooperating non-member is authorized to formulate its own definition of "shallow-set". Such shallow-set swordfish fleets are required to either i) use large circle hooks with offsets of $\leq 10^{\circ}$; ii) use whole finfish for bait; iii) apply an alternative measure approved by the WCPFC's Scientific Committee (SC); or iv) be granted an exemption by the WCPFC SC on the basis of minimal interactions.

Workshop Arrangements

A series of two four-day workshops designed to conduct a joint-analysis of the effectiveness of sea turtle mitigation in Pacific longline fisheries were held in Honolulu, Hawaii in February and November 2016. These workshops were convened by the Western and Central Pacific Fisheries Commission (WCPFC) with funding provided by the ABNJ (Common Oceans) Tuna project, and were attended by 38 participants from 16 countries with expertise in all three oceans, as well as invited IGOs and NGOs. Utilizing confidentially-held fishery observer data from Pacific Community (SPC) member countries, as well as data accessed under special confidentiality arrangements with Chinese Taipei, Japan and Reunion, SPC compiled a dataset representing over 2,300 turtles caught by 34 fleets across the Pacific between 1989-2015. Data were securely maintained and processed in real time during the workshops by two SPC analysts. As data access permissions expired at the close of the second workshop all results needed to be produced, discussed, agreed and documented in session.

[1] Although there is potential sea turtle mortality associated with FAD entanglement, anecdotal evidence suggests this is negligible in comparison to mortality rates in longline fisheries (Restrepo et al. 2014). Safe release methods are more straightforward in purse seine fisheries as compared to longline fisheries where there is likely to be a considerable danger of post-release trauma and death due to swallowed hooks and leaders (Parga 2012).

Modelling Approach
Three types of analyses were undertaken for leatherback, loggerhead, green and olive ridley turtles[2]: 1) estimating the effects of various operational variables on interaction rates at the set level; 2) estimating how turtle interaction rates vary by hook position within baskets; and 3) estimating the effects of various operational variables on turtle at-vessel mortalities. Post-release mortality was not considered due to a lack of available information. In addition to the three "building block" models, the workshops developed maps of sea turtle relative abundances for use in scaling model results to account for sea turtle "hotspots". All of this information was combined with estimates of fishing effort by fleet and fishing strategy to assess the effect of various packages of mitigation measures (scenarios) on the four threatened sea turtle species.

Determinants of Interactions and Mortalities
In the first "building block" model—the set-level model—there were a number of operational factors which were found to influence sea turtle interaction rates. These included hook type (both shape and size), bait species, the number of hooks between floats (i.e. a proxy for whether the hooks were set deep or shallow), and the number of hooks per set. The analysis of observer data found that use of large circle hooks (defined by the workshop as size 16/0 or larger) and the use of finfish bait were associated with significant decreases in interaction rates. In addition, two habitat variables, sea surface temperature and distance to land, were shown to be important in determining interactions between longline gear and some species. Increases in the number of hooks set, and decreases in the number of hooks between floats (i.e. shallower setting) were also found to increase the likelihood of sea turtle interactions.

The second model, which was run separately for deep and shallow set configurations, examined the degree to which the position of the hook in relation to the float in each basket determined the likelihood of sea turtle interactions. This was expected to be mainly a function of the depth in the water column, with the hooks closest to the floats fishing shallower and more likely to come into contact with sea turtles than those in the middle of the basket. This model was used to inform the workshop about mitigation measures involving removal of the first, or first and second, hooks adjacent to each float. After testing a number of formulations of the model, the workshop found that hook position-specific interactions depend mainly on the position of the hook relative to the float, and the number of hooks between floats (i.e. the depth of the set). Interactions were found to be increasingly likely for hooks closer to floats, i.e. for the shallowest hooks in the basket. Interactions were also increasingly likely as hooks between floats decreased, i.e. as the depth of the set decreased. Additionally, for deep sets only, the strength of the relationship between hook position and interaction probability varied between species, with a weaker relationship for leatherback sea turtles relative to green, loggerhead and olive ridley sea turtles, in accordance with expected species-specific habitat (depth) preferences. As a result, the reduction in interactions from removing the first and/or second hooks closest to the float in each basket was weaker for leatherback sea turtles.

The third model—the condition model—examined which factors influenced the likelihood that a sea turtle would be dead when hauled back to the vessel (at-vessel mortality). The probability that a sea turtle was alive decreased with longer soak times, higher sea surface temperatures, longer floatlines and a greater number of hooks between floats. The latter two factors are likely to be characteristic of deeper sets in which sea turtles, if hooked, may not be able to reach the surface for

[2] Hawksbill sea turtles (*Eretmochelys imbricata*), though found in the Pacific, generally have a coastal distribution that minimizes their interaction with tuna longline fisheries and were thus not included in the analysis conducted by the workshop.

respiration and thus asphyxiate. Leatherback sea turtles had a significantly higher likelihood of survival than any of the other three species, and hook shape (classified as circle, "J" or tuna/Teracima) was also found to be important in determining survival rates.

Relative Abundance Mapping

In the first workshop participants generated preliminary species-specific maps of the relative abundances of the four sea turtle species. However, these maps were based mainly on species ranges and nesting site information and did not necessarily capture where there may be open ocean sea turtle "hotspots". As much of the sea turtle tracking research is still in progress, an online, two-round Delphi survey was used to solicit information from experts and develop a consensus relative abundance map for each species. In the first round, participants were given the four species-specific maps produced by the first workshop and asked to adjust them based on their own knowledge. A second round involved asking participants to comment on first round maps and either agree with them or alter them further. Each species' map had input from 11-14 experts and despite the limits to existing knowledge, the Delphi process provided a useful way of peer-reviewing the initial maps and gaining consensus on the best available information. Although this information is known to be incomplete, the Delphi maps were able to suggest higher abundances in areas close to sea turtle nesting sites and help extrapolate into sea turtle habitat that was not represented in the observer dataset. These maps were used in combination with the set-level model to predict interactions under optimal habitat conditions (based on sea surface temperature and distance to land) and then scale the results downward in areas of relatively less-suitable habitat.

Testing of Mitigation Scenarios

The outputs from the three "building block" models (set-level, hook position and condition (at-vessel mortality)) were considered to represent the status quo, i.e. current (2010-2015) baseline conditions under the existing implementation of CMM 2008-03 as understood by the workshop. A simulation model and a series of scenarios were used to test the degree to which additional mitigation would reduce sea turtle interactions and mortalities compared to the status quo. Each scenario consisted of a set of assumptions about which mitigation measures would be applied to different sectors (fleet-fishing strategy combinations) and the effort currently fished by each sector (2010-2015 annual average) drawn from regional fishery management organization databases. Tested mitigation measures included use of large (16/0 or larger) circle hooks, finfish bait, and removal of the first, or first and second, hook positions closest to the float in each basket (and combinations of two or more of these measures). Modelled sectors included shallow swordfish and shallow "other" (non-swordfish targeting fleets), and deep albacore and deep "other" (non-albacore targeting fleets) with the distinction between shallow and deep operations set at 10 hooks between floats. Gear configurations known from observer data were used to characterize these sectors' current and prospective fishing operations and were extrapolated where necessary. Results were produced in relative terms, i.e. as proportional reductions under each scenario as compared to a status quo estimate, for both the Western Central Pacific only and for the Pacific as a whole.

Workshop Conclusions

The following conclusions were drawn from the results of the scenarios:

1. For all four sea turtle species there were limited reductions in interactions, and even more limited reductions in at-vessel mortalities, resulting from strengthening mitigation for the fisheries already regulated by CMM 2008-03 (i.e. self-identified shallow-set effort targeting swordfish).

2. For all four sea turtle species, shallow-set mitigation measures deliver substantially weaker reductions in at-vessel mortalities compared to deep-set mitigation measures, due to lower at-vessel mortalities in shallow set fisheries, and because some CCMs have already implemented mitigation based on CMM 2008-03 for their shallow swordfish fisheries.
3. For all four sea turtle species, deep-set mitigation measures deliver stronger reductions in at-vessel mortalities compared to interactions. This is a result of the fact that sea turtles caught in deep sets have a higher probability of at-vessel mortality due to asphyxiation as documented in previous studies.
4. For all four sea turtle species combined, deep set mitigation measures result in a greater reduction in overall interactions than shallow set mitigation measures. Although interactions are more likely in shallow sets, the greater amount of effort in deep set fisheries (4 times greater effort in deep set than shallow set fisheries) contributes to this result. However, for one species (loggerhead sea turtle), the maximum reduction obtained with deep set mitigation is less than the maximum reduction obtained with shallow set mitigation.
5. For all four species the effect of large (size 16/0 or larger, as assumed in the simulations) circle hooks in reducing interactions is greater than the effect of fish bait, but the degree of difference varies across species and across sectors (i.e. shallow versus deep).
6. In reducing both interactions and at-vessel mortalities in deep set fisheries, mitigation involving removal of the hook position closest to the float is similar in effectiveness to changing to finfish bait. Removal of the two hook positions closest to the float is similar in effectiveness to changing to large circle hooks.
7. The effect of removing the two hook positions closest to the float is greater than removing only the first hook positions closest to the float. However, the difference varies by species with the weakest mitigation effect for leatherback sea turtles that tend to interact with longline gear at greater depth.

The workshop also developed a number of recommendations for observer data collection, sea turtle habitat studies, further quantitative analyses, and cooperation with other sea turtle conservation and management initiatives.

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1 Introduction

There are seven species of sea turtles and six of these are considered to be threatened with extinction according to IUCN Red List criteria (i.e. critically endangered, endangered or vulnerable; IUCN 2015). Factors such as human consumption of meat and eggs, predation on eggs, nesting disturbance, climate change, marine pollution and boat collisions all have contributed to declines in sea turtle populations, but interaction with fishing gear is considered to be one of the most serious threats (FAO 2010; Wallace et al. 2011, 2013). Starting over ten years ago, a number of tuna Regional Fisheries Management Organizations (t-RFMOs) have adopted conservation and management measures that require mitigation to reduce the impacts of fishing operations on sea turtles. However, the effectiveness of these measures remains largely unexamined due to a lack of information on implementation, compliance and species-specific interaction and mortality rates (Clarke et al. 2014).

The Areas Beyond National Jurisdiction (ABNJ, or Common Oceans) Tuna Project is a Global Environment Facility (GEF)-funded, FAO-implemented programme of work designed to encourage and reinforce sustainable tuna fisheries. One of the three main components of the project focuses on mitigating bycatch and ameliorating adverse impacts on biodiversity. Taking its cue from a work plan developed by the Joint t-RFMO Technical Working Group-Bycatch, the ABNJ Tuna Project aims to progress prioritized research on sea turtle bycatch mitigation through encouraging data sharing and collaborative analysis (Joint Tuna RFMOs 2011). Funding has been allocated to WCPFC and The Pacific Community (SPC) under the ABNJ work programme to support two sets of workshops on bycatch mitigation issues facing t-RFMOs. The first workshops (February 2016 and November 2016) are designed to focus on assessing the effects of mitigation on interaction and at-vessel mortality rates of sea turtles in pelagic longline fisheries.

The WCPFC Secretariat announced the first workshop on 14 October 2015, calling for nominations of participants from WCPFC members and cooperating non-members (CCMs). After confirming participation from Australia, Chinese Taipei, the Cook Islands, the European Union, Fiji, Federated States of Micronesia, Japan, Republic of the Marshall Islands, Palau, Papua New Guinea, Tonga and the United States, remaining spots in the workshop were proposed to be offered to representatives from:

- Countries with experience in sea turtle-longline interactions including Brazil, Uruguay and Mexico;
- the Secretariats of the four other t-RFMOs (i.e. Commission for the Conservation of Southern Bluefin Tuna (CCSBT), the Inter-American Tropical Tuna Commission (IATTC), International Commission for the Conservation of Atlantic Tunas (ICCAT), and the Indian Ocean Tuna Commission (IOTC));
- three inter-governmental organizations with an interest in sea turtle issues (SPREP (Secretariat of the Pacific Regional Environment Programme), the Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC), and the Indian Ocean South-East Asian Sea Turtle Memorandum of Understanding (IOSEA)); and
- two non-governmental organizations which expressed interest in attending the workshop (the International Seafood Sustainability Foundation (ISSF) and the Worldwide Fund for Nature (WWF)).

Of these invited parties, representatives from Brazil, Uruguay, SPREP, the IAC, ISSF and WWF participated in the first workshop (*Annex A*). The same participants were invited for the second workshop but due to personnel changes some participants were substituted for those who could no longer attend. In addition, for the second workshop two WCPFC CCMs (Fiji and Japan) requested to send two participants, and a participant from China was recruited (*Annex B*).

The two workshops convened from 16-19 February 2016 and from 3-8 November 2016 in conference facilities graciously provided by the Western Pacific Regional Fishery Management Council (WPRFMC) in their offices at 1164 Bishop Street, Honolulu, Hawaii, United States. Ms Kitty Simonds, Executive Director of WPRFMC, greeted participants with opening remarks at each workshop, in both cases stressing the importance of the topic to regional fisheries management and welcoming the provision of sound scientific advice to inform management decision-making. Appreciation is expressed to staff of the WPRFMC who supported both workshops. The workshops were chaired by Dr Shelley Clarke, Technical Coordinator-Sharks and Bycatch for the ABNJ Tuna Project based at the WCPFC Secretariat. Dr Eric Gilman (Hawaii Pacific University/Palau) and Neville Smith (SPC) assisted with rapporteuring.

Special arrangements were agreed to protect the confidentiality of shared data. Under these arrangements, SPC compiled contributed data into a common format and securely maintained these data throughout the workshop without releasing them to any of the other participants. All data analyses were conducted by the SPC statistician (Mr. Tom Peatman) and SPC database manager (Mr Sylvain Caillot) with results being projected onto a screen for discussion by the workshop. It was agreed that metadata and data products which have been confirmed to be in compliance with national data confidentiality rules (e.g. the three-vessel rule) could be shared amongst participants and included in the meeting report. It was announced that participation in the workshop involved an implicit commitment not to copy or otherwise reveal data or discussions from the workshop directly related to data to non-participants via social media or other technology. Participants were asked to respect this commitment in order to avoid jeopardizing this and future data sharing opportunities.

The data used in this workshop consisted of:

- WCPFC Regional Observer Programme data;
- National observer programme data held by SPC on behalf of its members (i.e. American Samoa, Australia, Cook Islands, Federated States of Micronesia, Fiji, France, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Mariana Islands, New Zealand, Palau, Papua New Guinea, Pitcairn Island, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, the United States, Vanuatu, and Wallis and Futuna);
- National observer programme data provided by Japan and Chinese Taipei under data confidentiality agreements specific to these two workshops; and
- Observer data for the Reunion longline fishery provided by Institut de Recherche pour le Développement (IRD) through an existing data confidentiality agreement with SPC.

More information on the dataset is provided in Section 3.

2 Workshop Objectives

As announced in WCPFC Circulars 2015/72 and 2016/15 the workshops were designed to focus on evaluating mitigation techniques for sea turtle bycatch in pelagic longline fisheries. It was initially proposed that the workshop analyses focus on mitigation involving depth, soak time, hook width and shape, and bait type and include the species of sea turtles most likely to interact with pelagic longline tuna fisheries in the Pacific: green (*Chelonia mydas*, TUG), leatherback (*Dermochelys coriacea*, DKK), loggerhead (*Caretta caretta*, TTL) and olive ridley (*Lepidochelys olivacea*, LKV). The first workshop was intended to characterize current (or "baseline") sea turtle interaction and mortality rates under existing fishing operations. The second workshop would then work toward altering the baseline scenario defined in the first workshop to represent various mitigation options, and if possible, determine whether any of the simulated mitigation schemes are able to reduce any unacceptable impacts to sea turtle populations to acceptable levels (assuming a baseline risk assessment is available from other sources).

2.1 Status of Pacific Sea Turtles

A number of presentations were given at the first workshop to provide background and context for the intended analyses.

S. Clarke gave a presentation by S. Clarke and E. Gilman providing a general overview of the status of and threats to sea turtles and a quick summary of potential techniques to mitigate these based on Clarke et al. (2014). Of the six sea turtles that are currently listed in threatened categories by the IUCN Red List, only Kemp's ridley (*Lepidochelys kempii*) is not found in the Pacific. Hawksbill sea turtles (*Eretmochelys imbricata*, TTH), though found in the Pacific, generally have a coastal distribution that minimizes their interaction with tuna longline fisheries and were thus not included in the analysis conducted by the workshop. All sea turtles have been listed by the Convention on International Trade in Endangered Species (CITES) on Appendix I (i.e. a trade ban) for several decades now, and all except the flatback (*Natator depressus*) are listed by the Convention on Conservation of Migratory Species (CMS) Appendices I & II. There is one inter-governmental convention for the Americas (IAC) and there are two international memoranda of understanding on sea turtle conservation, one for Atlantic Africa, and one for the Indian Ocean/Southeast Asia. When threats from fishing are considered as a whole, the species identified as most at risk in the Pacific were the hawksbill, leatherback and loggerhead sea turtles. However, a ranking of threats specific to longline fisheries listed the South Pacific population of loggerheads of greatest concern, with olive ridley populations in the Eastern Pacific also at high risk from bycatch (but the population status at a lower threat level).

Options to mitigate threats from longline fisheries to sea turtles vary by species and life-stage but generally involve avoiding preferred habitat, altering the attraction to bait and gear, and reducing the sea turtles' propensity to ingest or entangle in gear. There have been many experiments investigating one or more of these aspects and results from different fisheries and conditions are sometimes contradictory. However, most of the evidence suggests that circle hooks, particularly those which have large minimum widths and are large relative to mouth size of susceptible sea turtles, can reduce hooking interactions or mortality or both. Use of finfish bait, rather than squid bait, is also a promising mitigation technique. Avoiding preferred habitat has potential as a mitigation option but in many cases what constitutes preferred habitat is difficult to understand or predict, especially when related to dynamic oceanographic variables. This mitigation option could also have implications for reduced catches of target species which could be a barrier to its implementation. It is important to realize that while mitigation seeks to reduce interaction rates overall, scenarios under which hooking rates do not decrease but mortality rates do (e.g. with safe release) may be considered positive outcomes. It was acknowledged that in cases where post-release mortality rates are not well understood, mortality rates estimated up to the point of safe release may under-estimate actual mortality.

The first workshop was urged to consider what data are available to inform its analyses and to formulate questions that can be addressed using the data available. In addition to planning for more in-depth analysis of these data in the second workshop, participants were asked to identify any critical data gaps to be filled in the short- and long-term.

In discussion of this presentation it was clarified that disturbance of nesting habitat, human consumption of meat and eggs, and predation on eggs can be a major threat to turtles but the situation with regard to this threat has improved in recent years with increased nesting beach protection in some areas and so attention has turned to mitigating the threats from fisheries. The severity of the threat posed by interaction with fisheries varies by species but is considered to be particularly of concern for leatherback turtles given their status.

I. Kinan-Kelly (National Oceanic and Atmospheric Administration (NOAA) Pacific Islands Regional Office (PIRO)) presented a review of sea turtle nesting and habitat information. Sea turtles are a long-lived, late maturing, highly migratory species with variable life histories. Total sea turtle population estimates are problematic due to a lack of demographic information. Nesting females are the most accessible component of sea turtle populations and can be used as population indices. Published nesting population trends and available pelagic habitat use information were summarized for the key species as follows:

- Green turtles are widely distributed, occurring in over 140 nations and nesting in at least 80 countries. In the Indo-Pacific, there may be approximately 200,000 females nesting annually at over 230 nesting locations (Seminoff et al. 2015). In the Pacific, a number of nesting populations have been monitored over a relatively long time period (20-30+ years) that provides evidence of increasing, decreasing, or stable nesting trends, although overall populations are reduced from historic levels or continue to be threatened by habitat loss, directed capture of turtles and eggs, fishery interactions, and climate change (Seminoff et al. 2015). Some published and unpublished satellite telemetry data exists for Pacific green turtles suggesting that post-nesting females tend to migrate west from Oceania nesting beaches to foraging habitats of the western Pacific (Craig et al. 2004; Kolinski et al. 2014; Parker et al. 2015; NMFS PIFSC, unpublished data).
- Olive ridley turtles have two primary nesting strategies: arribada (mass) nesting and solitary, with the species defined by a western Pacific population that nests primarily in India and an eastern Pacific population which nests primarily in Mexico, Costa Rica and Nicaragua. The eastern Pacific population may consist of approximately 2.5 million nesting females and the western Pacific population may be comprised of approximately 300,000 females nesting annually with additional unquantified nesting activity in northern Australia (NMFS and USFWS 2014; Limpus 2009). Overall, eastern Pacific nesting trends are increasing and recovering from directed turtle harvest that occurred prior to 1990s, although the overall population is reduced from historic levels and continues to be threatened by habitat loss, harvest, and fishery bycatch (NMFS and USFWS 2014).
- Leatherback turtles in the Pacific are comprised two demographic populations identified through genetic studies (Dutton et al. 2007) occurring in the western and an eastern Pacific. The western Pacific meta-population nests in Indonesia, Papua New Guinea and Solomon Islands where approximately 500-600 females may nest annually (Tapilatu et al. 2013; Pilcher 2011). The eastern Pacific meta-population nests primarily in Mexico and Costa Rica where approximately 150-200 females may nest annually (IUCN Marine Turtle Specialist Group. 2013a). The western Pacific population is declining at a rate of 6% per year with an overall 78% decline at Jamursba-medi the primary nesting beach in Indonesia (Tapilatu et al. 2013). The eastern Pacific population is also struggling with a nesting trend declining by 90% since monitoring began during the 1980s (IUCN Marine Turtle Specialist Group 2013a). These declining trends are a significant conservation concern. Primary threats to Pacific leatherback turtles include impacts at nesting beaches (egg harvest and

beach erosion), fishery interactions in coastal and pelagic fisheries, and climate change (IUCN Marine Turtle Specialist Group 2013b; NMFS and USFWS 2013).

- Loggerhead turtles in the Pacific Ocean are comprised of two distinct population segments, a North Pacific and a South Pacific population. Approximately 500 to 1,000 loggerheads may nest annually in Japan and roughly 2,000-5,000 loggerheads may nest annually in eastern Australia and New Caledonia (Y. Matsuzawa, Sea Turtle Association of Japan, pers. comm. unpublished; UNEP/CMS/COP11 2014). While both populations are currently stable or increasing, both are significantly reduced from historic levels and recovering trends are at least partially dependent on continued conservation and management efforts to protect nesting turtles and their habitats, and to mitigate coastal and pelagic fishery interactions (IUCN Marine Turtle Specialist Group 2015).

Over the last two decades, dedicated efforts have been made to better understand sea turtle pelagic habitats through satellite telemetry and oceanographic research. The most comprehensive migratory and foraging habitat information currently exists for North Pacific loggerhead and western Pacific leatherback turtles, with olive ridley turtle habitat use the least understood (Bailey et al. 2012; Kobayashi et al. 2008; Polovina et al. 2004, 2006). The North Pacific loggerhead turtle pelagic migratory habitat is highly correlated with sea surface temperature (18°C isotherm) and the Kuroshio Extension Current, with coastal foraging hotspots located in Baja California, Mexico and the East China Sea (Howell et al 2008; Kobayashi et al. 2011; Seminoff et al. 2014). The marine habitats for the western Pacific leatherback turtle subpopulation extend north into the Sea of Japan, northeast and east into the North Pacific to the west coast of North America, west to the South China Sea and Indonesian Seas, and south into the high latitude waters of the western South Pacific Ocean and Tasman Sea (Benson et al. 2011). Identifying where pelagic longline fisheries overlap with sea turtle migratory and key foraging habitats, and implementing fishery mitigation measures to reduce interactions and mortality, are key to supporting ongoing recovery efforts.

C. Siota (Secretariat of the Pacific Regional Environmental Programme (SPREP)) introduced her organization's Turtle Research and monitoring Database System (TREDS). TREDS was developed to be the overarching database system for turtle research and monitoring conducted by member countries and territories of SPREP. It is a tool that can be used to compile and manage data from various governments, NGOs, community groups and researchers who undertake turtle research, monitoring and tagging. The use of TREDS ranges from simple turtle tagging and nesting surveys (recording basic information) to more complex research that collects genetics samples, uses laparoscopy to determine reproductive status, and satellite telemetry for tracking migration movements. The information derived from TREDS on important turtle nesting and foraging sites can be useful to superimpose with fishery interaction data during the workshop. SPREP would like to seek advice from participants on how TREDS can be upgraded and improved to better capture and store information on bycatch of turtles.

2.2 Status of Mitigation Implementation

Y. Swimmer (NOAA, Pacific Islands Fisheries Science Center (PIFSC)) described progress with an ongoing NOAA project analysing United States longline-sea turtle interaction data in order to provide useful insights for the workshop's own analysis. Her analysis focuses on using observer data from two U.S. pelagic longline observer data sets (North Atlantic / Gulf of Mexico and Hawaii-based in the North Pacific) to investigate the efficacy of sea turtle mitigation methods. Observer programs have been monitoring these fisheries since the early 1990's, and mitigation measures were put in place in 2004. A number of US longline fisheries were temporarily closed during 2000/2001 until 2004 during which time mitigation methods aimed to reduce sea turtle bycatch were identified. Fisheries were re-opened in 2004 with modified gear (e.g., relatively large circle hooks and fish bait), a higher mandatory rate of observed monitoring, requirements for training in handling of protected species, as well as (in some cases) a hard cap (limit)on sea turtle captures. The species most vulnerable to capture and for which mitigation measures were intended were loggerhead and leatherback turtles. The closure provided both complexity in data analysis (due to confounding variables) as well as an opportunity to assess the efficacy of mitigation measures before and after the regulations were put in place. A variety of methods were used to analyze 20+ years of observer data, including general linear models (GLMs), general additive models (GAMs), and non-parametric statistics to identify factors related to the fishery dynamics that affect turtle catch risk and magnitude of bycatch rate of loggerhead and leatherback turtles. In sum, factors most associated with sea turtle capture risk were related to location, hook type, and bait type for both leatherback and loggerhead turtles, with circle hooks (vs. J) and fish (vs squid) associated with lower risk. Hook depth was also a factor for loggerhead turtles, with shallower hooks predicted to increase catch risk. The presentation aimed to provide a roadmap for this type of analysis that can inform fisheries managers on effective conservation tools.

In discussion of this presentation the workshop noted the importance of observer programmes providing reliable species identifications. It was considered that it may be possible to assign a data quality code based on factors such as whether there was photo-validation of a sighting, whether the identification was based on onboard examination, and the time of day of the sighting. It may also be necessary to improve the training of observers and increase the availability of training materials, or consult experts on whether sightings are credible.

There was also some discussion about the trade-off in modelling for this workshop between retaining incomplete data records which weaken the dataset with missing data versus discarding these records to obtain a smaller, but more consistent dataset. While both approaches have strengths and weaknesses, there was general consensus that retaining data is preferable to discarding it, particularly when analyzing data for rare events like turtle bycatch.

S. Clarke then presented a review of available information on implementation of the WCPFC's sea turtle mitigation conservation and measure (CMM 2008-03). This CMM specifies mitigation in both longline and purse seine fisheries, and is the only one of the five t-RFMO sea turtle measures to require changes in fishing behaviour in longline fisheries. These changes are limited to fleets fishing in a shallow-set manner for swordfish, and each CCM is authorized to formulate their own definition of "shallow-set". Such shallow-set swordfish fleets are required to either i) use large circle hooks with offsets of $\leq 10^{o}$; ii) use whole finfish for bait; iii) apply an alternative measure approved by the WCPFC's Scientific Committee (SC); or iv) be granted an exemption by the WCPFC SC on the basis of minimal interactions. A January 2016 review of WCPFC's member and cooperating non-member (CCM) Annual Reports-Part 2 for CMM 2008-03 determined that nine CCMs declared that they had fleets fishing for swordfish in a shallow-set manner. One of these has left the fishery (and had no observer coverage) and one was granted an exemption by the WCPFC SC. Of the remaining seven CCMs, five provide details of what mitigation measures were implemented when. Of these five, three report implementation of mitigation from 2013 onward which provides at most one year of observer data currently available (one of these has no observer coverage). The remaining two reported mitigation as of 2005 and 2010, respectively. This situation, in combination with the facts that i) other CMMs may have switched to or from circle hooks or finfish bait in recent years for other reasons; and ii) most of the gear characterization in the observer data is available for 2008 onward, means that a before-CMM and after-CMM comparison is problematic. It was recommended instead that the workshop consider focusing on a) establishing a current baseline of interactions and mortalities (e.g. 2010-2015); b) understanding how these relate to potential mitigation practices (e.g. hook and bait types); c) identifying key parameter and process uncertainties; and d) determining priorities for future analyses.

Acknowledging the difficulties associated with a before- and after- analysis, the workshop generally agreed that the proposed objectives were appropriate, but there was considerable discussion about what kind of baseline would be constructed and which factors should be considered when standardizing interaction and mortality rates. The workshop noted that it is important to take account of effort patterns in the fishery. For example, it is not unexpected that areas with high fishing effort would have high bycatch of turtles compared to areas with low fishing effort. The models should examine how many hooks are fished per set in different fleets, and perhaps consider the proportion and distribution of hooks observed within a trip.

Participants discussed that if a limited number of gear features are used to characterize fishing operations, it is possible that two fleets might be considered to be very similar when actually they have very different fishing behaviours. For this reason, it is important to understand fishing strategies, for example using expert knowledge, rather than classifying operations solely based on observer-collected data fields.

It was noted that it might be difficult to estimate baseline (or current) values given the poor state of our knowledge and low recording rates of currently used hook sizes and offsets. Even if observers record this information, which is not always the case, measurement protocols or units vary between observer programs, and these hook features may vary from one manufacturer to another even if the hook type and hook size remain constant.

Some participants queried whether an estimated baseline should be a single value for the Western and Central Pacific Ocean (WCPO) or Pacific as a whole, or whether it would be better to focus on critical habitat areas and monitor interactions and mortality over time in these areas. Given that any mortality estimate would necessarily under-estimate post-release mortality, it was suggested that estimating baseline interactions was a higher priority than estimating baseline mortalities.

In the second workshop S. Clarke explained that the WCPFC's Twelfth Technical and Compliance Committee meeting, held in September 2016 had included the WCPFC's sea turtle measure (CMM 2008-03) in its Compliance Monitoring Review (CMR) for the second time. (The first time was in 2014 when compliance for fishing year 2013 was evaluated). The 2016 evaluation for fishing year 2015 was conducted in closed session and the details will not become a matter of public record until the WCPFC adopts the final CMR at its annual session in December 2016. Nevertheless, the discussion helped to clarify the WCPFC Secretariat's understanding of which CCMs consider that they "fish for swordfish in a shallow-set manner", noting that under the measure CCMs are required to self-identify by "establishing and enforcing their own operational definitions of shallow-set swordfish longline fisheries". Based on the best judgement of the WCPFC Secretariat (including both public and non-public sources of information which are in many cases subject to interpretation), the following CCMs self-identify as having longline vessels that fish for swordfish in a shallow-set manner: Australia, the European Union (Spain, Portugal), Japan, New Zealand, Chinese Taipei and the US (Hawaii). Of these, New Zealand has applied for and been granted an exemption under paragraph 7b of CMM 2008-03 on the basis of minimal observed interaction rates.

This information is important for construction of the fleet groupings for modelling scenarios examining various mitigation options, i.e. both mitigation methods and their application across fleets (see Section 3.2.2). CMM 2008-03 presents three conditions for applicability and the fleet groupings are based on filters that reflect these three conditions: whether the gear is set shallow or deep, whether swordfish is potentially the primary target, and whether the fleet self-identifies as having longline vessels that fish for swordfish in a shallow-set manner. The shallow-deep filter and the potential for swordfish targeting filter are discussed in Section 3.2.2 below. For the self-identification filter it was proposed that only vessels flagged to Australia, European Union member States (Spain, Portugal), Japan, New Zealand, Chinese Taipei and the US (Hawaii) would pass the filter for self-identification (see preceding paragraph for rationale). It should be noted that for each of these CCMs there is a portion of effort for which CMM 2008-03 is considered applicable and portion of effort for which it is not (e.g. deep effort and/or shallow effort potentially targeting a species other than swordfish). The purpose of defining an effort group that is considered to be already subject to the requirements of CMM 2008-03[3] is to be able to assess the incremental effects of extending the current applicability to other effort (again, e.g. deep effort and/or shallow effort targeting a species other than swordfish). In the case of New Zealand's exemption, this is assumed to be permanent, i.e. no scenarios examine any change in New Zealand's sea turtle mitigation measures. These assumptions are simply for the sake of this modelling exercise and carry no compliance implications.

2.3 Updated Literature Review of Effects of Longline Hook and Bait Types on Sea Turtle Catch Rate, Anatomical Hooking Position and At-Vessel Mortality Rate

In the second workshop, E. Gilman (Palau) presented the findings from a literature review on the effects of hook shape, hook size and bait type on sea turtle catch rates, at-vessel mortality rates and anatomical hooking position (Gilman and Huang 2016). Main findings from the study were:

- Fish versus squid for bait lowered catch rates of leatherback sea turtles and individual species of hard shelled turtles;
- Fish bait also reduced hard-shelled turtle deep hooking;
- Wider circle hooks reduced both leatherback and hard-shelled turtle catch rates relative to narrower J and tuna hooks, and reduced the proportion of caught hard-shelled turtles that were deeply hooked;
- Wider circle hooks with fish bait reduced leatherback and hard-shelled turtle catch rates relative to narrower J and tuna hooks with squid bait;
- Wider versus narrower circle hooks reduced hard-shelled sea turtle catch rates and deep hooking.

The study identified research designed to assess single factor effects (i.e., when only one factor is variable, and all others are fixed), in particular for hook shape and minimum hook width, and for hook and bait effects on anatomical hooking position and survival rates, as highest priorities to fill remaining gaps in understanding. The presenter noted that the findings from the workshop models can be compared to the compiled findings in the literature review. However, the workshop modeling is restricted to explicitly accounting for only factors and covariates available in the pooled observer datasets. For example, if the workshop dataset lacks leatherback catch data on circle, J and tuna hooks of same size, this prevents this workshop from inferring what effects the single factor hook shape had on leatherback catch rates. The presenter also noted that regional simulations of the effects of alternative tuna RFMO options for prescribed longline gear elements may have large fishery-specific variability in effects on sea turtle interactions, catch and mortality rates of other at-risk taxa, and economic viability.

Participants noted that little is known about the gear configurations for shallow set mahi mahi fisheries. Therefore, the effects of mitigation measures in those fleets will be more uncertain.

[3] including those subject to, but granted an exemption from, CMM 2008-03 (i.e. New Zealand)

3 Data Preparation and Modelling Approach

3.1 Characterizing Longline Fishing Fleets in the WCPO

Longline observer coverage for the WCPO tuna fleets varies between fleets and areas, and may not be representative of longline fishing operations as a whole. In an effort to improve the gear characterization information available for this workshop, SPC prepared summaries of pertinent operational information for 26 fleets (i.e. flag State-setting strategy (deep/shallow) combinations) based on observer data. These summaries included information on the mode or average for time of day of setting, soak time, number of hooks set, hooks between floats, float length, branchline length, use of wire leaders, use of shark lines, lightsticks, bait type, hook type, hook size and hook offset. The WCPFC Secretariat asked CCMs in WCPFC Circular 2016/03 to check the summaries and verify whether they accurately represent each fleet's actual gear profile.

Summaries were sent individually to Australia (AU), China (CN), Cook Islands (CI), Federated States of Micronesia (FM), Fiji (FJ), French Polynesia (PF), Japan (JP), Kiribati (KI), Korea (KR), Marshall Islands (MH), New Caledonia (NC), New Zealand (NZ), Papua New Guinea (PG), Samoa (WS), Solomon Islands (SB), Tonga (TO), Chinese Taipei (TW), United States (Hawaii (HW)/American Samoa (AS)), and Vanuatu (VU) for checking. The gear characterization summaries, including corrections received and updates at the second workshop, are shown in Table 1. These data were taken as representative of each fleet for the modelling scenarios defined in Table 15 (see Section 4.5).

3.2 Overview of the Workshop Data Sets

3.2.1 *Catch and Condition Data*

S. Caillot (SPC) gave an overview of the datasets made available for the first workshop. Data from multiple sources were compiled ranging from regional and national longline observer programmes maintained by SPC to additional datasets shared by countries. Templates developed by SPC and used by observers in the region were presented along with the overall architecture of the turtle dataset. Challenges encountered during the incorporation of the datasets provided in multiple formats were explained and the different steps (harmonization, validation, optimization) to obtain a consistent and consolidated database representing more than 148,000 observed sets, 311 million observed hooks and 2,300 turtle interactions were described. Workshop participants were asked to check the information for the fleets they know and advise SPC of any pertinent background information (e.g. their fleets do not use shark lines and thus do not record whether or not such lines are used; or, the data are available but were simply not provided to SPC). New information was incorporated and the table was further refined during the workshop.

SPC presented maps of catch (interactions) by species for loggerhead, leatherback, olive ridley and green turtles for shallow and deep longline sets (Figures 1-4). It was noted that the timeframe and coverage represented in each of the observer programs vary. It was also noted that it would be interesting to consider which grid squares have recorded catches of more than one species over time. Participants were asked to check the maps to determine if any of the points shown were dubious (e.g. several green turtles reported north of 30°N). There was consensus that the modelling approach should take into account species-specific differences to the extent possible given the available dataset. For example, it may be possible to include species-specific interactions for certain variables within a model fitted to turtle interactions for all species.

Prior to the second workshop Japan provided additional observer data for the Eastern Pacific Ocean under the same confidentiality conditions as the previously provided data. These additional data represent 31 trips with 1,927 sets and 79 sea turtles interactions. The time coverage is from 2007 to 2015 and the geographic extent covers from 150°W to 87°W and from 19°S to 28°N.

The following tables present summaries of the datasets available for the second workshop by:

- flag and potential covariates (Table 1);
- data source and sea turtle species (Table 2);
- sea turtle condition, fate and biological data collected (Table 3); and
- sea turtle numbers by depth of set, and by depth of set and condition (Figure 5).

More detail on sea turtle condition, fate and biological data by year and species is provided in *Annex C*.

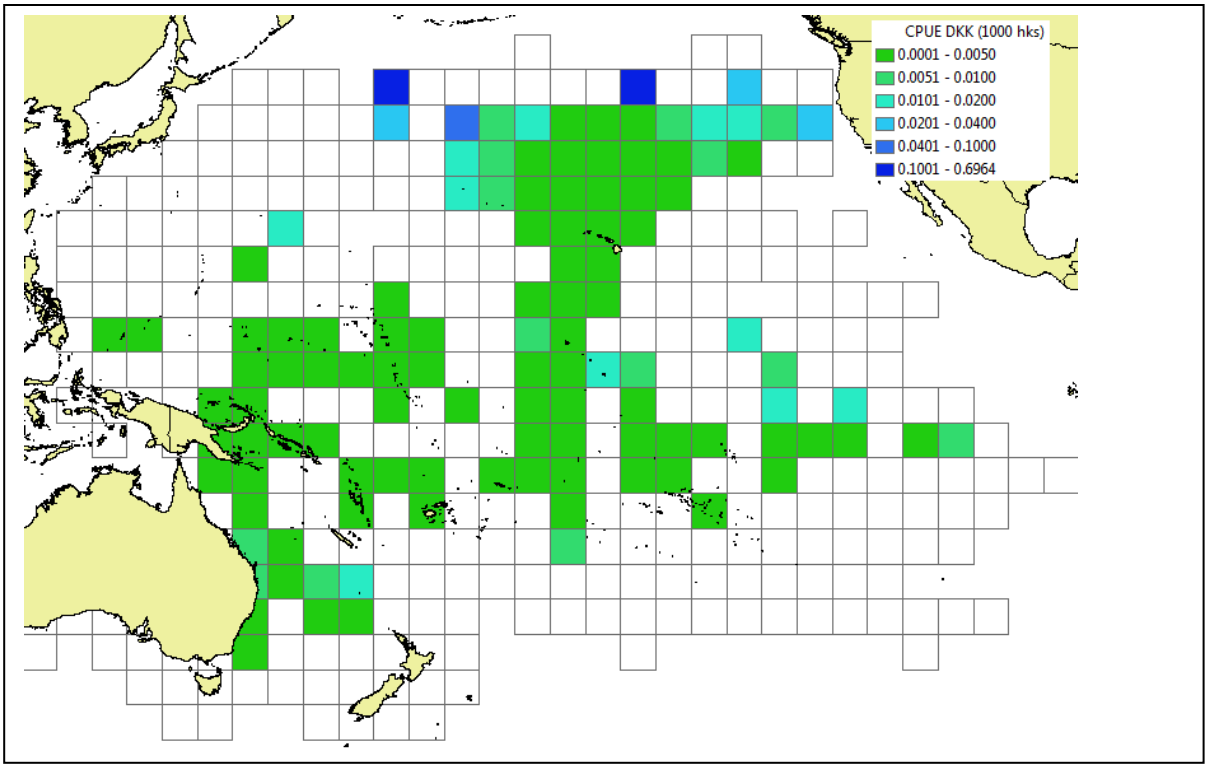

Figure 1. Catch per unit effort of leatherback sea turtle (*Dermochelys coriacea*, DKK) by 5º x 5º grid based on observer data for deep and shallow longline fisheries in the workshop dataset, 1989-2015 (updated at the second workshop). Empty cells indicate where there was fishing effort on observed trips but no catch of this species.

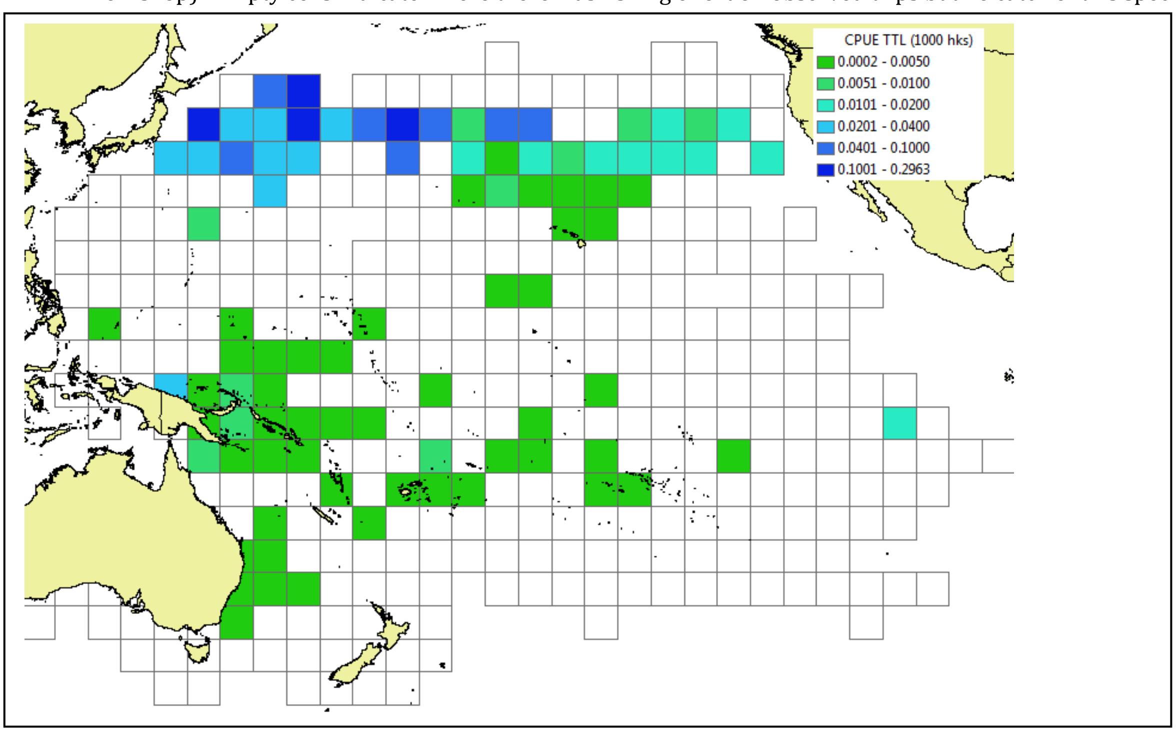

Figure 2. Catch per unit effort for loggerhead sea turtle (*Caretta caretta*, TTL) by 5º x 5º grid based on observer data for deep and shallow longline fisheries in the workshop dataset, 1989-2015 (updated at the second workshop). Empty cells indicate where there was fishing effort on observed trips but no catch of this species.

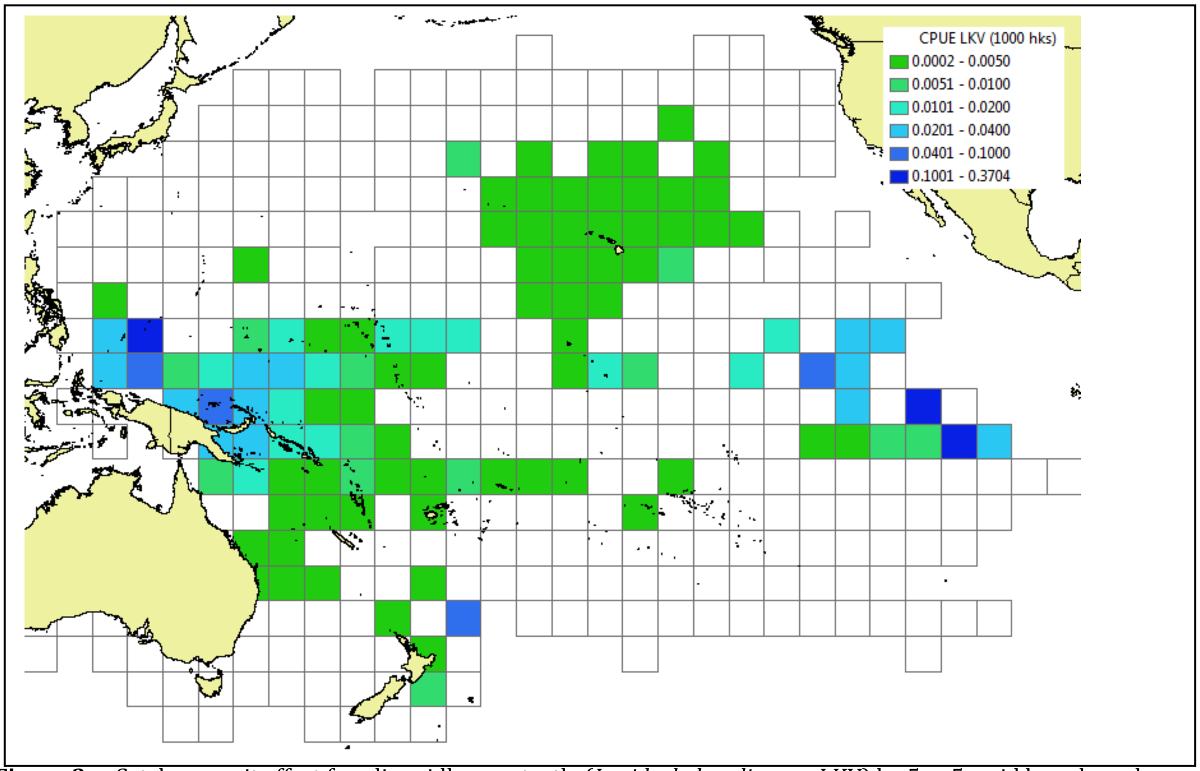

Figure 3. Catch per unit effort for olive ridley sea turtle (*Lepidochelys olivacea*, LKV) by 5º x 5º grid based on observer data for deep and shallow longline fisheries in the workshop dataset, 1989-2015 (updated at the second workshop). Empty cells indicate where there was fishing effort on observed trips but no catch of this species.

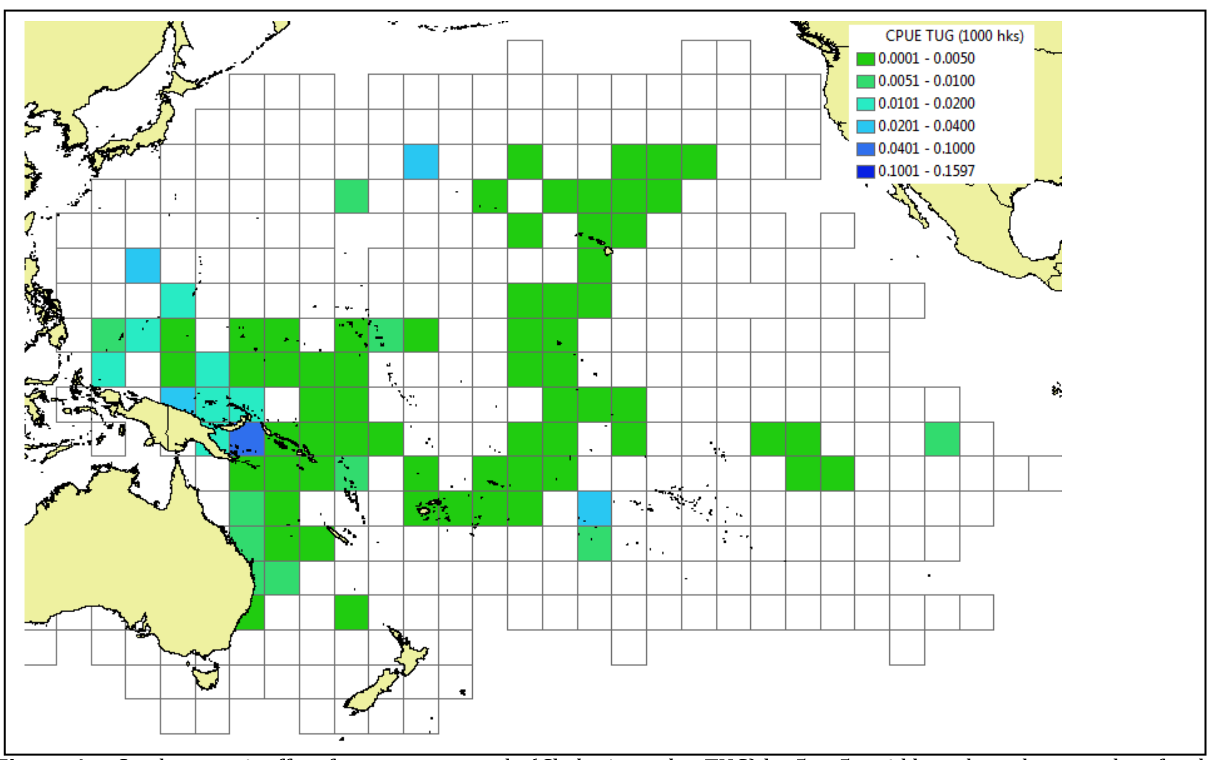

Figure 4. Catch per unit effort for green sea turtle (*Chelonia mydas*, TUG) by 5º x 5º grid based on observer data for deep and shallow longline fisheries in the workshop dataset, 1989-2015 (updated at the second workshop). Empty cells indicate where there was fishing effort on observed trips but no catch of this species.

Table 1. Summary of data availability and gear characteristics for the fleets (updated at the second workshop) based on data provided for years since 2009 (most recent year varies by fleet). Note that a fleet's characterization may be based on data from different observer programmes which may collect data on gear characteristics differently (e.g. for Japanese vessels fishing in Pacific Island countries' EEZs under the SPC/FFA observer and Japanese vessels fishing on the high seas under Japan's own national observer programme). Column headings shaded yellow denote those columns containing actual data. Column headings shaded orange denote those columns containing information on the availability of data (for example, 100% indicates that all records of a specific dataset have information for this data field whereas 0% indicates that none of the records of a specific dataset have information for this data field). Orange-headed columns have cells shaded green to red showing a gradient of data availability. It should be noted that red shading may result from either missing data or intentional non-collection of data (for example, that gear has been discontinued in that fleet). Column headings shaded blue denote columns which are categorical breakdowns of orange-headed columns to the left (note that mixed fish/squid bait would be counted as both "fish" and "squid". (See Section 3.1 for fleet abbreviations).

Country	Depth	Avg hks flt	Float length %	Hks float %	Wire trace %	Light sticks %	Shark lines %	Target species %	Hook type %	Hook size %	Circle hk %	Tuna hk %	J hk %	Other hk %	Offset Y %	Bait %	Squid bait %	Fish bait %	Mack bait %	Other bait %	Position %	Date %	Soak time %	Set nb	Turtles cond. %	Turtles fate %	Turtles length %	Turtles nb
AS	deep	29	100	100	100	99	0	100	100	99	97	2	0	0	98	96	0	95	0	0	100	100	100	4215	100	100	91	34
AU	deep	19	78	99	0	67	0	80	80	76	76	0	0	3	0	100	84	63	2	0	100	100	19	680	93	100	87	33
AU	shallow	8	67	99	0	46	0	69	68	57	56	0	0	11	0	99	70	61	18	0	99	99	28	865	100	100	100	12
CK	deep	29	99	100	97	29	25	99	94	81	56	30	0	6	7	98	0	93	9	0	99	99	96	1135	95	100	65	20
CN	deep	21	97	97	0	100	91	100	69	69	6	62	0	0	0	95	19	77	37	0	99	99	4	3080	91	100	75	36
FJ	deep	35	99	99	93	48	63	92	90	85	73	11	0	4	25	98	1	87	19	0	99	99	97	3547	100	100	85	71
FJ	shallow	9	93	100	100	93	93	93	100	100	100	0	0	0	0	93	0	93	0	0	100	100	93	2	0	0	0	0
FM	deep	23	100	100	100	10	5	100	55	45	14	41	0	0	14	100	10	25	74	0	100	100	100	33	0	0	0	0
FM	shallow	8	100	100	100	31	3	100	87	34	0	87	0	0	0	100	100	72	0	0	100	100	100	56	57	100	100	19
FR	deep	33	100	100	100	0	0	100	100	100	100	0	0	0	0	98	0	98	0	0	100	100	100	22	0	0	0	0
FR	shallow	6	0	100	0	97	0	100	97	0	25	0	22	49	0	100	98	3	55	0	100	100	97	130	32	100	11	140
HW	deep	25	99	99	100	99	0	100	100	99	84	15	0	0	99	95	0	94	0	0	100	100	100	21888	100	100	80	63
HW	shallow	4	100	100	100	99	0	100	100	100	100	0	0	0	100	99	0	1	98	0	100	100	100	8668	99	100	40	124
JP	deep	18	98	100	0	39	0	0	86	3	9	76	0	0	0	97	39	71	66	0	100	100	92	4835	98	0	72	236
JP	shallow	3	100	100	0	22	0	0	100	0	6	84	0	9	0	100	9	12	100	0	100	100	100	200	97	0	44	84
KI	deep	23	100	100	99	14	56	99	99	68	31	36	0	31	5	99	79	99	96	0	100	100	99	627	100	87	62	8
MH	deep	24	93	100	100	61	0	100	73	51	44	22	6	0	0	98	15	82	22	0	100	100	97	133	85	100	57	7
NC	deep	30	99	100	82	41	9	99	90	86	79	9	0	1	0	99	0	99	1	0	100	100	97	1035	83	100	100	6
NR	deep	20	100	100	100	0	0	100	100	100	0	100	0	0	0	100	0	100	0	0	100	100	100	9	0	0	0	0
NZ	deep	13	98	100	0	0	0	82	98	8	87	0	0	10	0	34	34	14	0	0	100	100	92	654	66	100	0	3
NZ	shallow	9	99	100	0	0	0	78	16	2	15	0	0	0	0	32	32	31	12	0	100	100	97	932	100	100	0	4
PF	deep	37	96	99	91	33	21	86	89	72	37	37	2	12	7	99	0	99	1	0	99	99	98	2773	90	100	72	11
PG	deep	17	100	100	100	0	0	100	100	100	0	100	0	0	0	100	0	100	0	0	100	100	100	28	0	0	0	0
PG	shallow	4	99	100	100	0	98	91	100	88	5	87	7	0	17	99	0	56	92	18	99	99	97	826	96	97	95	99
PW	deep	15	86	100	100	58	32	100	100	100	0	100	0	0	41	100	73	40	100	0	100	100	100	8	100	100	100	2
PW	shallow	6	99	100	96	27	23	97	94	92	0	92	0	1	0	98	48	65	72	0	100	100	94	180	98	100	89	66
SB	deep	25	99	100	100	24	40	99	100	88	75	21	0	3	17	98	25	92	22	0	99	99	97	1283	96	99	82	117
TO	deep	23	99	100	96	7	57	96	95	88	67	20	0	6	25	100	0	74	31	1	100	100	98	380	100	100	50	4
TO	shallow	7	100	100	100	0	38	100	49	49	10	38	0	0	49	100	88	74	89	24	100	100	83	115	100	100	100	1
TW	deep	17	99	100	100	0	0	98	100	97	12	33	52	2	0	99	8	98	1	0	99	99	96	12272	92	100	89	97
TW	shallow	6	100	100	100	5	0	100	100	100	42	56	0	0	0	100	61	93	7	0	100	100	98	504	100	100	100	9
VU	deep	23	98	100	95	37	81	81	96	75	5	79	0	10	9	97	0	94	6	0	99	99	89	1006	100	100	100	2
VU	shallow	7	100	100	83	78	75	50	100	57	0	57	0	42	0	98	0	97	0	1	100	100	96	105	100	100	0	1
WS	deep	32	98	100	100	0	6	100	100	100	100	0	0	0	0	100	0	79	20	0	100	100	99	23	100	100	100	1

Table 2. Summary of the observer dataset (updated for the second workshop) showing trips, sets, geographic range and sea turtles caught (SPC (n=1,040), Hawaii (n=632), Japan (n=322), Reunion (n=142), Chinese Taipei (n=111), American Samoa (n=39) and China (n=37). Species codes: DKK (*Dermochelys coriacea*), FBT (*Natator depressus*), KEZ (*Chelonia agassizii*), LKV (*Lepidochelys olivacea*), TTH (*Eretmochelys imbricata*), TTL (*Caretta caretta*), TTX (unspecified turtle species), TUG (*Chelonia mydas*)).

yy	Trips nb	Sets nb	Avg_lon	Min_lon	Max_lon	Avg_lat	Min_lat	Max_lat	Turtles nb	DKK_nb	LKV_nb	TTL_nb	TUG_nb	FBT_nb	KEZ_nb	TTH_nb	TTX_nb
1989	12	166	165.5	145.5	182.5	-38.5	-47.5	-16.5	1	0	0	0	0	0	0	0	1
1990	26	347	165.5	147.5	181.5	-38.5	-49.5	-23.5	1	0	0	0	0	0	0	0	1
1991	72	927	154.5	96.5	181.5	-37.5	-45.5	-22.5	1	0	0	0	0	0	0	0	1
1992	77	1048	155.5	112.5	181.5	-35.5	-47.5	8.5	0	0	0	0	0	0	0	0	0
1993	113	1520	150.5	111.5	209.5	-36.5	-48.5	10.5	7	1	0	0	0	0	0	0	6
1994	142	1623	164.5	111.5	211.5	-20.5	-48.5	43.5	43	8	3	11	2	0	0	0	19
1995	136	1565	171.5	112.5	219.5	-12.5	-48.5	44.5	47	4	9	19	4	0	0	0	11
1996	130	1589	170.5	110.5	232.5	-14.5	-47.5	40.5	58	9	11	29	4	0	0	1	4
1997	138	1750	174.5	110.5	231.5	-12.5	-48.5	39.5	50	12	7	22	1	0	0	0	8
1998	126	1720	179.5	134.5	232.5	-6.5	-48.5	39.5	80	7	15	49	2	0	0	2	5
1999	102	1406	177.5	96.5	229.5	-7.5	-48.5	34.5	52	4	12	21	10	0	0	0	5
2000	184	2260	186.5	140.5	231.5	5.5	-49.5	37.5	60	10	12	22	11	0	0	5	0
2001	341	3979	189.5	138.5	223.5	6.5	-49.5	34.5	37	4	10	7	2	0	0	0	14
2002	653	5757	187.5	144.5	224.5	4.5	-49.5	32.5	37	6	7	6	3	0	0	3	12
2003	607	5511	189.5	103.5	263.5	2.5	-48.5	35.5	23	6	6	0	3	0	0	1	7
2004	636	6424	189.5	100.5	222.5	5.5	-48.5	55.5	79	17	35	6	11	0	0	2	8
2005	797	8718	191.5	104.5	234.5	11.5	-48.5	41.5	65	18	13	15	15	1	0	2	1
2006	684	7948	187.5	55.5	242.5	2.5	-48.5	36.5	119	17	31	21	9	1	0	3	37
2007	660	7890	190.5	131.5	251.5	6.5	-49.5	38.5	123	11	65	21	14	5	0	3	4
2008	673	7997	191.5	46.5	256.5	8.5	-46.5	40.5	122	8	57	11	36	0	0	9	1
2009	642	7921	193.5	49.5	239.5	6.5	-46.5	38.5	87	20	48	5	11	0	0	3	0
2010	664	8614	195.5	46.5	256.5	5.5	-58.5	45.5	124	19	62	18	15	1	0	6	3
2011	668	10320	196.5	42.5	273.5	11.5	-46.5	41.5	178	35	60	30	31	1	1	6	14
2012	695	12966	190.5	45.5	278.5	2.5	-46.5	45.5	249	26	101	52	41	1	0	14	14
2013	803	18018	193.5	49.5	273.5	1.5	-45.5	41.5	288	45	94	40	62	1	0	14	32
2014	779	15433	194.5	48.5	255.5	2.5	-45.5	42.5	347	40	97	127	29	5	0	10	39
2015	147	2091	189.5	49.5	250.5	-13.5	-24.5	41.5	45	4	7	17	9	0	0	4	4
TOTALS:									**2323**	331	762	549	325	16	1	88	251

Table 3. Summary of the observer dataset (updated at the second workshop) by sea turtle species, condition, fate and biological data collected (see *Annex C* for disaggregated data). Species codes: DKK (*Dermochelys coriacea*), FBT (*Natator depressus*), KEZ (*Chelonia agassizii*), LKV (*Lepidochelys olivacea*), TTH (*Eretmochelys imbricata*), TTL (*Caretta caretta*), TTX (unidentified turtle species), TUG (*Chelonia mydas*) (n=2,323). "Condition" refers to the turtle's status at its first observation by the observer; "fate" refers to the turtle's status at its final observation by the observer.

sp_code	Cond_Alive	Cond_Unknown	Cond_Dead	Fate_Discarded	Fate_Retained	Fate_Escaped	Fate_Unknown	With_measure	No_measure	Sex_Male	Sex_Female	Sex_Indeterminate	Sex_Unknown	adult	juvenile	intermediate	unknown	all_records
DKK	222	86	23	301	11	2	17	56	275	17	7	1	306	1.2%	12.1%	3.6%	83.1%	331
FBT	10	0	6	16	0	0	0	11	5	3	5	2	6	0.0%	0.0%	68.8%	31.3%	16
KEZ	1	0	0	0	0	0	1	1	0	0	0	1	0	0.0%	0.0%	100.0%	0.0%	1
LKV	292	88	382	623	19	3	117	662	100	174	193	48	347	0.0%	0.0%	86.9%	13.1%	762
TTH	46	11	31	85	2	1	0	64	24	19	22	1	46	8.0%	56.8%	8.0%	27.3%	88
TTL	269	237	43	438	10	1	100	390	159	35	39	13	462	0.7%	58.7%	11.7%	29.0%	549
TTX	129	31	91	150	14	2	85	128	123	63	22	10	156	0.0%	0.0%	51.0%	49.0%	251
TUG	156	37	132	289	30	0	6	265	60	57	57	15	196	4.6%	72.3%	4.6%	18.5%	325
TOTAL	1125	490	708	1902	86	9	326	1577	746	368	345	91	1519					2323

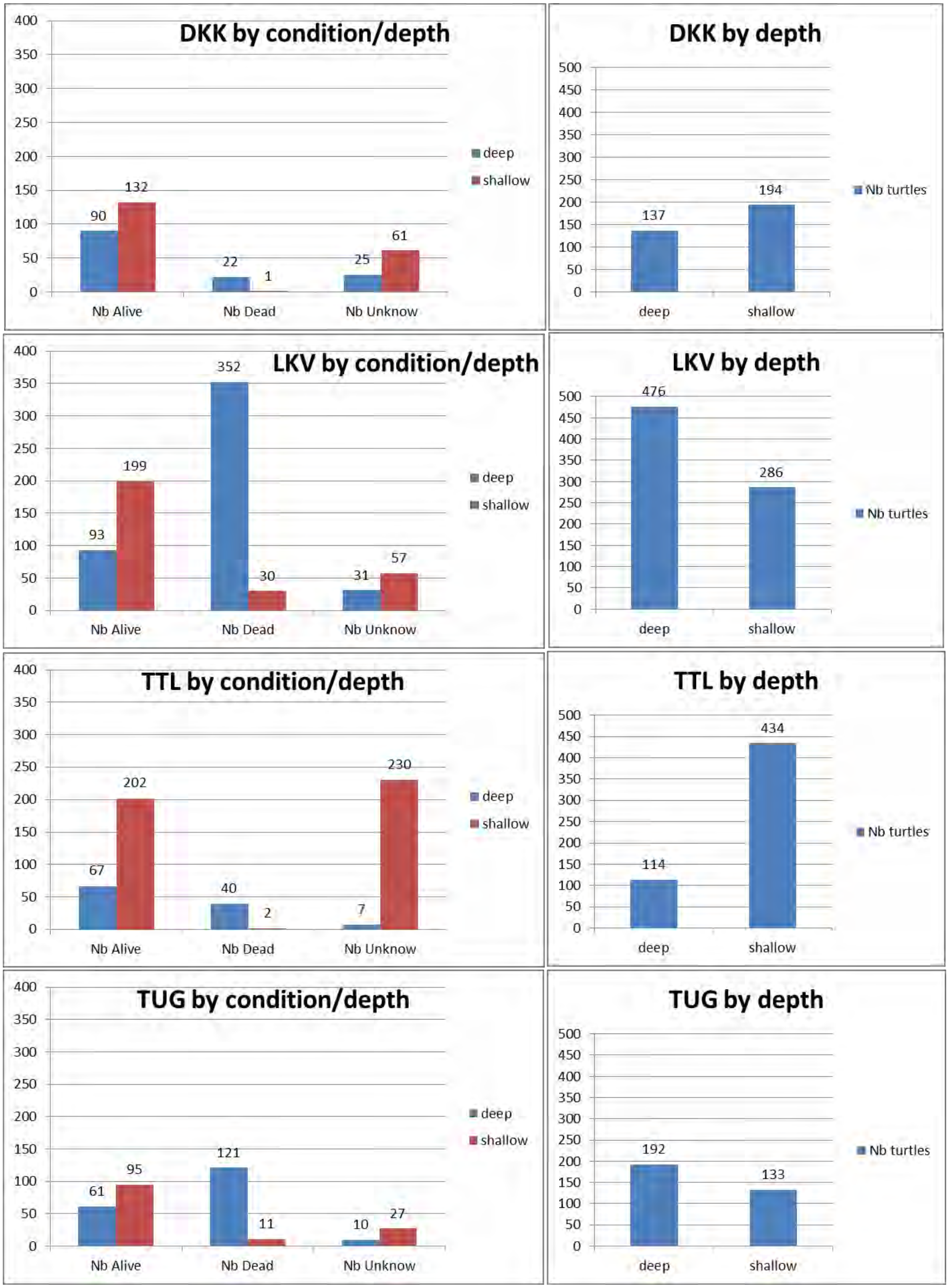

Figure 5. Plots of the number of turtles (Nb) caught in deep and shallow sets (left) and the number dead, alive and of unknown condition by depth of set in the observer dataset (updated at the second workshop). Species codes: DKK (*Dermochelys coriacea*), LKV (*Lepidochelys olivacea*), TTL (*Caretta caretta*), TUG (*Chelonia mydas*). Turtles for which the depth of the set is unknown (2 TTH and 1 TTL) are not shown here.

3.2.2 *Effort Data*

In addition to organizing the observer gear characteristics and catch records, SPC compiled effort statistics for use in extrapolating the observer data to the fishery as a whole when running the simulation models. Data were compiled for the period 2010-2015 to best reflect recent practice and the period of applicability of CMM 2008-03.

In a series of iterative steps, maps of longline effort were generated for the baseline period, disaggregated by deep and shallow fishing strategies. The shallow effort was split between effort targeting swordfish and all other shallow effort (i.e. mahi mahi, sharks, etc), referred to as shallow-swordfish and shallow-other respectively. The deep effort was split between that targeting albacore (deep-albacore), and effort targeting all other species (deep-other, i.e. bigeye and other tuna species), to allow flexibility in simulations to apply different hook category mitigation measures on the two deep components. The method for developing the effort maps is described below.

For the purposes of the simulation modelling, the western and central Pacific Ocean (WCPO) was defined as the WCPFC convention area. The Eastern Pacific Ocean (EPO) was defined as the IATTC convention area, minus the overlap with the WCPFC convention area. Effort maps for the WCPO and EPO were generated using different approaches as described below, due to differences in data availability for the two regions.

WCPO effort maps were generated using the following approach (Figure 6). Catch effort data which had hooks between floats (hbf) information (e.g. disaggregated catch effort data) were extracted from SPC's Catch and Effort Query System, at a 5x5° resolution for the baseline period (2010-2015) Effort with less than or equal to (<=), and strictly greater than (>), 10 hbf was considered to be shallow, and deep, respectively (Section 4.5.1). The proportion of effort that is fished shallow and deep varies spatially and temporally, and by flag, as a consequence of different fishing strategies. Consequently, the proportions of deep and shallow effort were calculated for each flag, 5x5° grid and quarter, where possible. However, there were flag, grid and quarter combinations with no hbf information available, corresponding to approximately 15% of the total effort. In these instances, the following approach was implemented:

- If available, calculate the average deep and shallow proportions for that flag and 5x5° grid (i.e. aggregated over quarters); otherwise,
- If available, calculate the average deep and shallow proportions for that flag and 10x10° grid; otherwise,
- Calculate the average deep and shallow proportions for that flag and 5° latitudinal band.

The resulting deep and shallow proportions were then applied to reported effort for each flag, quarter and 5x5° grid to obtain spatial maps of deep and shallow effort. Shallow effort was attributed to shallow-other, with the exception of members self-identifying shallow swordfish effort (Section 2.2). For these self-identifying members, flag-specific reported swordfish catches at a 5x5° and quarterly resolution were divided by average flag-specific swordfish catch-per-unit effort to back-calculate shallow-swordfish effort. The remaining shallow effort from self-identifying members was attributed to shallow-other. All shallow effort between 15 °S and 20°N and west of 170 °W was assumed to be shallow-other, to ensure that shallow-swordfish effort was constrained to regions where swordfish targeting occurs. Flag-specific deep albacore effort was estimated by calculating the proportion of albacore, yellowfin and bigeye tuna reported catch (in number) accounted for by albacore effort at a 5x5° and quarterly resolution. The remaining deep effort was attributed to deep-other. Observer data for Australian-flagged vessels suggested some deep-set targeting of swordfish and this was considered to be best grouped with the deep-other effort for that fleet. It was noted that shallow set longline effort in the WCPO represents ~20% of total effort (<1% shallow swordfish effort, >19% shallow other effort), with ~80% of effort represented by deep set longliners (26% deep albacore effort; 54% deep other effort).

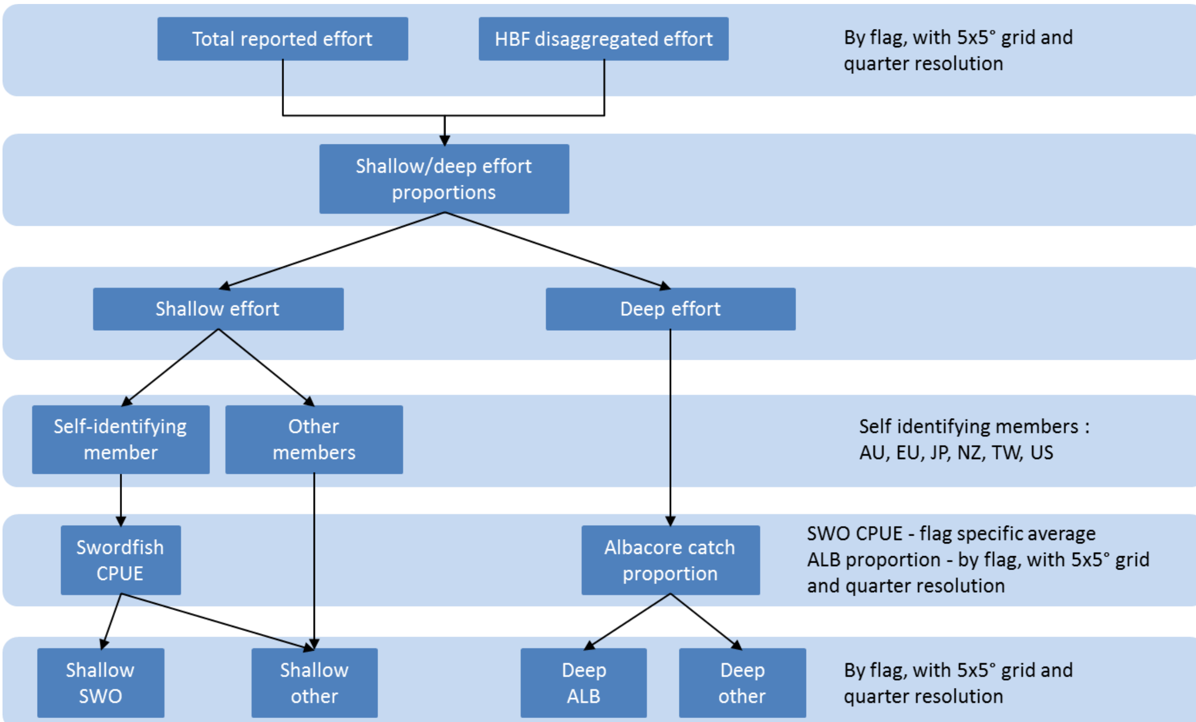

Figure 6. Summary of the process used to obtain effort maps for the WCPO. HBF = hooks between floats

IATTC effort maps were generated using the following approach (Figure 7) and IATTC public domain aggregate longline catch and effort data available at http://www.iattc.org/Catchbygear/IATTC-Catch-by-species1.htm. Catch and effort data by hbf were not available for the EPO. Consequently, it was assumed that shallow effort in the EPO could be back-calculated from swordfish catches. Shallow effort for WCPFC members self-identifying shallow swordfish effort in the WCPO, and also fishing in the EPO, was estimated using available average flag-specific swordfish catch-per-unit effort to available flag-specific reported swordfish catches, at a 5x5° and quarterly resolution (as per the approach in the WCPO). As there are no means of separating the remaining effort into shallow-other and deep effort, all of this remaining effort was assumed to be deep effort. The split between deep-albacore and deep-other in the EPO used the same approach used for the WCPO. It is noted that IATTC's longline effort records only contain effort data for Belize, China, Spain, Japan, Korea, Mexico, French Polynesia, Chinese Taipei, the United States and Vanuatu and thus exclude longline fleets known to operate off the coasts of Central and South America. Recent steps have been taken to identify sources of catch and effort data for these fleets but the datasets are currently not available in the public domain (Siu and Aires-da-Silva 2016). The sea turtle models used in the workshops were thus limited to the data available in IATTC's public domain datasets.

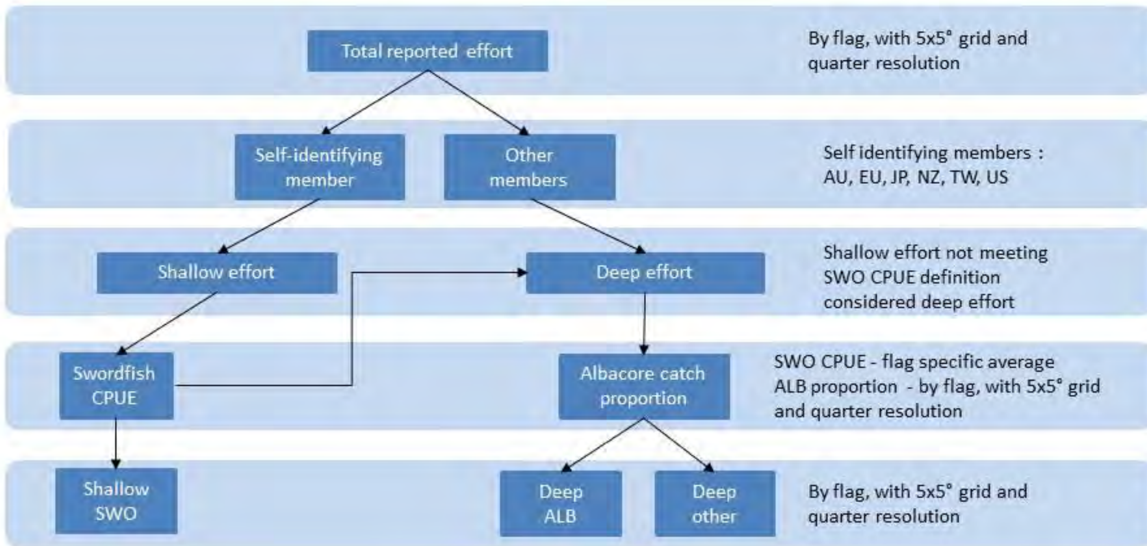

Figure 7. Summary of the process used to obtain effort maps for the EPO.

As a result of applying this algorithm to the Pacific as a whole, it was determined that shallow set longline effort represents ~19% of total effort (2% shallow swordfish effort, 17% shallow other effort), with ~80% of effort represented by deep set longliners (26% deep albacore effort; 55% deep other effort). The resulting deep and shallow effort maps for the Pacific are provided in *Annex D*.

The final step in preparing the effort data for input to the model of mitigation scenarios was to partition each estimate of effort by flag and fishing strategy/target species (e.g. shallow-SWO, deep-ALB) for each 5x5 degree cell into various gear configurations. This is necessary because some flags have multiple hook/bait combinations used for the same strategy/target species combination. This was accomplished by calculating the proportion of effort using each gear configuration (where there are data to confirm this) for the entire fishing ground as a whole, and applying these proportions to the effort maps described above (i.e. resulting from the processes in Figures 6 and 7 above). This approach makes the simplifying assumption for modelling purposes that observed (predominantly WCPO) longline effort is representative of total (Pacific-wide) longline effort, and that there is no spatial variation in gear configuration use for a given flag and strategy.

The workshop discussed the methodology used by SPC to derive the effort maps. It was acknowledged that the only shallow set swordfish fisheries known to be operating in the EPO are those by the United States and the European Union (Spain, Portugal). However, little is known about the current effort associated with other types of longliners operating there in terms of their gear configurations and propensity to interact with sea turtles. Participants also pointed out that for the Spanish fleet that operates in waters from 10-50°S in the Central and Eastern Pacific some information is available on total vessels, effort, observer coverages and turtle interactions by species, but the raw data are not available in a spatially disaggregated form and so cannot be included in the modelling.

Some participants cautioned against extrapolating gear configurations from observed to unobserved sets. For example, the US (Hawaii) shallow set longline fleet has 100% observer coverage and might tend to dominate the observed gear characteristics but at the same time not be representative of other unobserved longline fleets from other countries. SPC explained that flag-specific gear characteristics were only extrapolated from other flags if the gear characteristics for the flag in question are completely unknown. This was only the case for fleets from Chinese Taipei, the European Union (Spain, Portugal) and New Zealand. All three entities were requested to provide missing information and the latter two responded with information to inform the extrapolations. Other participants queried the appropriateness of extrapolating within flags suggesting that gear characteristics would be expected to vary not by flag, but by location of fishing or home base port. The workshop agreed that extrapolation of gear characteristics introduces a fair degree of uncertainty to the models but other than structuring the extrapolation by flag, there seemed to be no straightforward way of proceeding given the data available for the task.

3.3 Modelling Approach

The following modelling framework (Figure 8) was proposed based on a series of shark mitigation studies conducted by SPC (Bromhead et al. 2013, Caneco et al. 2014, Harley et al. 2015):

- modelling interaction rates at the set level as a function of explanatory variables to determine the effect of gear configurations on turtle interaction rates (Set-Level Model);
- modelling interaction rates by hook position to determine where turtle bycatch is found in relation to floats, i.e. is there a higher probability of turtle catch on hooks closer to a float (Hook Position Model);
- modelling the condition at capture of turtle bycatch to determine the effects of gear configurations on the proportion of turtles caught dead/alive (Condition Model); and,
- combining information from the three models in a simulation model to estimate overall turtle interactions and at-vessel mortalities (Simulation Model).

3.4 Discussion of Modelling Approach

There was general agreement that the Set-Level Model was an important building block for further estimates and thus a good place to initially focus the work. One participant considered that a trip level model would be a better framework given that sets within a trip are not independent; however, this participant agreed that a set-level model was also acceptable, particularly if there could be some accounting for potential spatial and temporal autocorrelation. SPC explained that the model data were sorted by trip and set number and tested for autocorrelation. If autocorrelation was detected in the model residuals then adjustments or alternative models were considered. It was also noted that the maximum number of records was used for each of the following models, however, if covariate information was lacking for certain records, those records would be excluded during the modelling process. Discussion of the other models was postponed until the workshop was ready to take them up (see following sections).

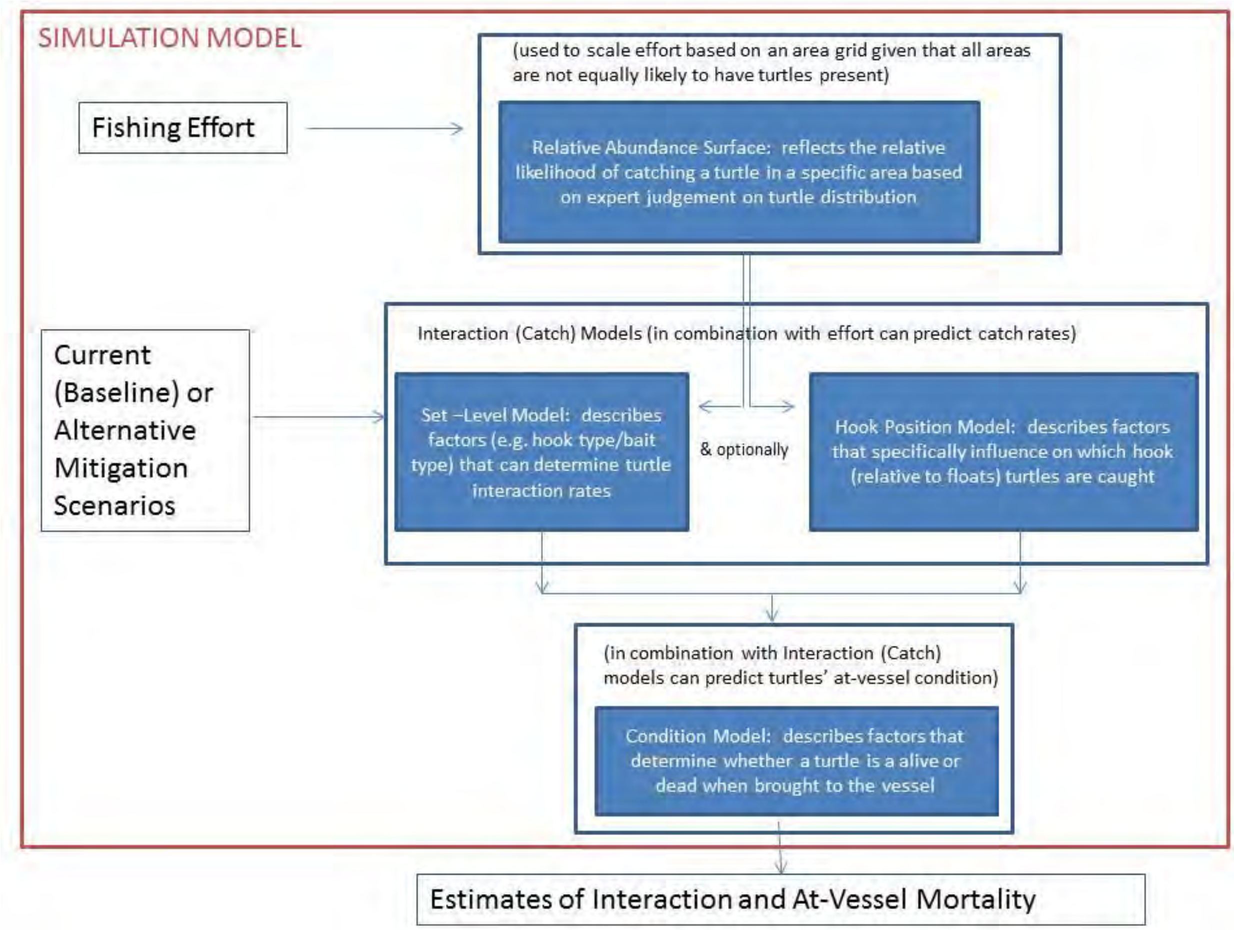

Figure 8. Schematic diagram of the simulation model and its components.

4 Joint Analysis

4.1 Modelling Longline Sea Turtle Interactions at the Set Level (Set Level Model)

4.1.1 *First Workshop Outcomes*

SPC presented further details on the Set-Level Model. There was agreement that modelling the presence/absence of turtle interactions separately from positive interactions was required, due to the zero-inflated nature of the dataset. The workshop agreed with the proposed use of GAMs and on the distributions to be used for the positive-catch portion of the model.

SPC presented maps of catch (interactions) for loggerhead, leatherback, olive ridley and green turtles for shallow and deep longline sets separately (Figures 1-4). It was noted that the timeframe and coverage represented in each of the observer programs vary. It was also noted that it would be interesting to consider which grid squares have recorded catches of more than one species over time. Participants were asked to check the maps to determine if any of the points shown were dubious (e.g. several green turtles reported north of 30°N). There was consensus that the modelling approach should take into account species-specific differences to the extent possible given the available dataset. For example, it may be possible to include species-specific interactions for certain variables within a model fitted to turtle interactions for all species.

The workshop discussed various ways of handling hook depth as a variable in the model. Two potential options were to *a priori* divide sets into shallow and deep categories or to use the number of hooks between floats (hbf) as a variable thereby allowing for a greater degree of distinction. Acknowledging previous work by K. Bigelow and others that suggests that hooks in practice fish considerably shallower than would be expected based on theory alone (Bigelow et al. 2006), various ways of accounting for the depth at which the hooks actually fished were discussed. SPC suggested clustering sets by targeting strategy, as defined by the recorded species composition, and then matching those strategies to the ranges of hbf fished. It was acknowledged that expert information about certain fisheries might help to refine these classifications. For example:

- it was clarified that the Papua New Guinea shallow set fishery was targeting sharks but closed in 2014.
- there is some shallow-set night-time fishing for bigeye tuna, often by Chinese Taipei vessels which operate in Palau and potentially elsewhere.

Some participants suggested that the depth at which the hooks fished could be approximated by variables that are (or could be) collected by the observer (e.g. floatline length, use of a line shooter, speed of setting, current speed, etc.). It was noted that floatline length would help determine the minimum depth of the shallowest hook in the set where a high proportion of turtle interactions occur. Other participants maintained that without TDRs (time depth recorders) estimating hook depth will be highly uncertain. Some participants considered that it might be important to take account of turtle life stage in the model by using available information on turtle size. SPC explained that there is some information on turtle size for a portion of the records, and turtle specialists agreed to provide SPC with some indicative size ranges of adults and juveniles for each species. The workshop noted that the sizes of turtles recorded as interacting with longline fisheries indicated spatial separation of juveniles and this is consistent with findings in other oceans. A table of size ranges for juvenile and adult stages of various species of turtles based on input from the workshop is shown in Table 4.

Table 4. Indicative sizes (rounded for this exercise) by life stage and maximum and minimum sizes for five species of sea turtles as prepared by the workshop from various published literature sources.

Species	Code	Maximal CCL (cm)	Size not possible	Maximal weight (kg)	Minimal CCL at first maturity Pacific (cm)	Juvenile	Intermediate	Adult
Caretta caretta	TTL	110	>120	150	85	<70	[70-90]	>90
Chelonia mydas	TUG	125	>135	250	85	<70	[70-90]	>90
Dermochelys coriacea	DKK	230	>260	900	120	<100	[100-130]	>130
Eretmochelys imbricata	TTH	100	>110	120	65	<60	[60-70]	>70
Lepidochelys olivacea	LKV	90	>100	70	55	<50	[50-60]	>60

It was noted that the WCPFC Regional Observer Programme does not clearly define what measurement method should be used for measuring the size of turtles. For example, Japan and the United States use straight carapace length (SCL) as measured using calipers, whereas Chinese Taipei uses curved carapace length (CCL) using a tape measure. This topic warrants further investigation to ensure data from different programmes can be appropriately compared or combined. SPC informed the workshop that according to the data currently available in the dataset prepared for this workshop no measurements were provided for 1057 turtles, SCL was provided for 240 turtles, CCL for 7 turtles, and carapace length given but no measurement type specified for 633 turtles. More data may be available from Hawaii and American Samoa; the United States will investigate these data.

Participants then identified operational variables considered most likely to affect turtle interaction rates and for which there were sufficient data to support estimation. The following variables were identified for an initial run of the Set Level Model:

- **Soak time** – it was suggested that soak time could be calculated as ((haul start-set end) + (haul end-set start))/2 to represent the midpoint between the time all hooks were fished and any hooks were fished (based on Carruthers et al. 2009);
- **Time of day of set** – it was noted that the same time of day of set could represent variable times before or after dawn or dusk based on season and latitude. Therefore times should be adjusted if possible to account for this;
- **Hooks between floats (hbf)** – it is recognized this is an attempt to account for hook depth but will be inherently uncertain. However, since the observer data generally contain hbf it was considered useful to retain the greater amount of information in hbf rather than condensing into shallow/deep categories;
- **Bait type** – given that the mixed bait type (squid+fish) is more uncertain than the other categories due to the unknown proportion of the mixture, SPC agreed to attempt to use other information to refine the mixed bait type if possible;
- **Hook type** – SPC proposed to use three types: J, C (circle hooks) and T (a combination of tuna hooks and Teracima hooks);

- **Hook Size** – although there are considerable data gaps in the recording of hook size, as well as potentially some problems in determining the actual (rather than relative) size of hooks which are listed as shape + model number (rather than actual measurements), the workshop agreed that hook size should be accounted for somehow (see Table 5 for the result); and
- **Sea Surface Temperature (SST)[4]** – although it was acknowledged that this is not strictly an operational variable (though fishermen may target certain water temperatures), it was recommended that it may be necessary to retain it in the model to account for species specific habitat preferences of turtles.

Other variables, such as the use of lightsticks, were acknowledged to be potentially important in this model but data were insufficient to include them. This model was agreed as a starting point for further examination of residuals (to determine whether other variables should be considered) and to determine the significance of the selected variables (to determine whether they should be retained or dropped).

SPC presented the result of the initial run of the Set-Level model. Soak time was recalculated according to Carruthers et al. (2009; see above) but the algorithm to adjust the time of the start of the set relative to dusk/dawn was rather involved and could not be applied. This and other time adjustments (e.g. calculating the number of daylight hours that the hooks are fished) were deferred until there was more time available to address them properly. This situation also occurred for the partitioning of the mixed fish and squid bait type: it may be possible to glean more information about this bait category later but it was considered too time consuming to undertake during the workshop.

The preliminary model results showed, *inter alia*, that J hooks had lower catch rates than C hooks which were in turn lower than T (tuna and Teracima) hook catch rates. In addition, bait comprised of fish or a combination of fish and squid had lower catch rates than bait comprised of squid only. For the “habitat” variable SST, which was given an interaction term with species, the green and olive ridley turtles showed linear and increasing catch rates with increasing SST whereas leatherbacks showed no response to SST and loggerheads shown a non-linear relationship. The diagnostic Q-Q showed a good fit and all variables were significant with (in descending order) bait, hook type and species having the highest effect sizes. However, in some areas, there was a distinct lack of fit identified through a spatial surface fitted to the residuals of the preliminary model. When residuals were plotted spatially by species, the areas of poor predictions were shown to vary by species but were often in areas where observer data were scant.

Participants discussed a number of approaches to try to reduce the spatial residuals of the model, i.e. to improve the model fit in areas where the model substantially under- or over-predicted turtle interactions perhaps due to habitat factors that are not well informed by the observer data and are not fully captured by SST. These areas of poor prediction included areas in the Kuroshio Current off Japan for loggerheads, and the area north of Papua New Guinea for olive ridley turtles. The first approach tested was to re-run the model using a factor to identify the observer programme providing the data; this was similar to defining regions within the WCPO since each observer programme is centered in its own EEZ. (Use of a fleet factor instead of an observer programme

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[4] Based on past experience, SPC recommended that SST be derived from oceanographic data (1 degree latitude-longitude square month (Reynolds)) rather than using the observers’ measurement of SST, and the workshop agreed. Nevertheless it is acknowledged that deriving SST in this manner involves some uncertainty given the coarseness of the grid of the oceanographic data available.

factor, i.e. to take account of target strategies, was considered but dismissed due to the potential to conflict with the information signal from the operational variables in the model). This approach did not, however, significantly improve the spatial residuals and also introduced issues with correlated explanatory variables. Instead, it was considered that information on areas of likely higher turtle catch rates could be predicted by a relative abundance map (or a similarly constructed coarse grid) based on existing information and/or expert judgement. Although it was acknowledged that this could over-simplify what is actually a very complex and highly uncertain situation, it can serve as a starting point for further work to be conducted before the second workshop and beyond (see Section 4.4).

The workshop then addressed the issue of informing the model about hook size. Participants considered that rather than modelling observer-recorded hook type and hook size as two variables, that categories should be formed based on a combination of the two. After examining the available observer data on hook size and shape, and comparing to existing information (Gilman et al. 2012) on minimum width and other hook dimensions, a table was produced classifying hook type-hook size combinations as small or large (Table 5). There was also a brief presentation by R.A. Sauturaga (Fiji) on the differences between hook types and sizes. Participants were referred to the SPC Longline Terminal Gear Identification Guide (http://www.spc.int/coastfish/index.php?option=com_content&Itemid=30&id=347) for more information. Participants noted that the Japan tuna hook is probably the strongest hook design; other hooks, especially those that are larger and wider, may unbend when very large fish are hooked. European fleets have fished J-hooks for a long time whereas Asian fleets have traditionally used Japanese tuna hooks. It was noted that Teracima hooks are used in the mahi mahi fishery in Fiji (20% of hooks fished are Teracima hooks, with the remainder being circle hooks). Some evidence from Ecuador and the Mediterranean suggests rings on the hooks may increase bycatch. Hook size tends to be related to selectivity and thus targeting strategies, however it may be that hook gape may be more important than hook size in this regard. It was noted that historically (pre-2003) J-hooks and tuna hooks were classified using similar terminology. There may be a need to re-visit that classification prior to the division of effort amongst the fishing fleets using in the simulation model (see Section 4.1.2 for an example of this).

The model was then re-run with hook type and hook size combined into a hook category variable as follows: large circle hooks, small circle hooks, small J hooks and small T hooks. There were no data for large J or large T hooks (Table 5). The results showed a larger effect of hook category relative to bait type than in the previous version of the model. Large circle hooks and small J hooks had similar catch rates. Small circle hooks had similar catch rates to small T-hooks. This suggests that it may be that the overall size of the large circle hooks have more of an influence on hard-shelled turtle catch than the circle shape per se, though it was noted that for leatherback turtles (which comprise about 20% of the turtle records) the shape of the hook may be more important than its size.

Table 5. Some hook types and sizes (Gilman et al. 2012) and the category (S=small, L=large) assigned by the workshop to each.

	Hook type	Minimum Width (cm)	Category
1	Offset 3.6 sun tuna hook Tankichi	3.1	S
2	Non-offset 8/0 J hook Mustad	3.5	S
3	Non-offset 3.8 sun tuna hook Tankichi	3.6	S
4	Non-offset 3.6 sun tuna hook Tankichi	3.7	S
5	Offset 15/0 circle hook Lindgren-Pitman	3.8	S
6	Offset 3.8 sun tuna hook Tankichi	3.8	S
7	Offset 14/0 circle hook Lindgren-Pitman	3.8	S
8	Non-offset 9/0 J hook Mustad	3.9	S
9	Non-offset 15/0 circle hook Lindgren-Pitman	4.0	S
10	Offset 16/0 circle hook Lindgren-Pitman	4.4	L
11	Non-offset 18/0 circle hook Lindgren-Pitman	4.9	L
12	Offset 18/0 circle hook Lindgren-Pitman	4.9	L

Note: Only a few types and sizes of circle hooks were categorized as large. All other type and size categories of hooks not found in Table 5, such as Teracima hooks, were compared using the SPC Terminal Gear Guide (http://www.spc.int/coastfish/index.php?option=com_content&Itemid=30&id=347) and, and it was decided that these hooks probably belonged in the small category."

The workshop further considered the potential interaction between hook category and bait type. Participants theorized that it might be the case that combinations of hook categories and bait types might perform differently than estimated with additive effects. Participants also suggested that leatherback catch rates might be insensitive to bait type as they are often foul-hooked or entangled rather than hooked when taking bait. It was noted that when the United States implemented its sea turtle mitigation plan for the shallow set fishery it required large (18/0) circle hooks at the same time it prohibited J-hooks with squid bait. As a result, the combinations of large circle hooks and squid bait and J-hooks with fish bait are absent or rare in the dataset. Thus the dataset does not include data for comparing large circle hooks to J-hooks with the same kind of bait. Consequently it is likely that that is why the model fails to detect a difference between large circle hooks and J hooks. Participants also mentioned that the hook type and bait type combinations may be correlated to year given the way in which mitigation programs were phased in (see *Annex E* for more information on United States regulations).

Running the model with an interaction between hook category and bait showed that when using fish bait, small circle hooks had higher turtle interaction rates than large circle hooks. Participants noted that interpretation of the mixed fish-squid bait type was problematic as the proportions of the two bait types are unknown and the sample size is low. Nevertheless, it is useful to retain this mixed bait category in the model in order to be able to predict interactions for fleets which use mixed bait.

Participants then considered whether a species interaction with hook shape was warranted. This could account for the fact that leatherbacks are more likely to be foul-hooked on J hooks. A species interaction term with hook type resulted in a percent deviance explained of 19.3% and a species interaction term with hook category (i.e. hook type + hook size) resulted in a percent deviance explained of 19.8%.

A set-level model including hook category (type and size), bait type, hook category*species, time of set, soak time, hooks between floats, and SST*species was tentatively accepted by the workshop pending final checking. It was noted that an effort offset should be included to explicitly account for the number of hooks per set. SPC reported back to the workshop that adding an offset for effort did not appreciably change the results. Another aspect of the checking involved examining whether the interaction terms in the model substantially improved the model fit. In performing this check, SPC noted that the data available to support estimation of interaction terms for hook and bait categories are insufficient therefore it was agreed that these interaction terms would be removed from the model. It was also agreed that since set time is not meaningfully contributing to increasing the percent deviance explained in the set-level model it could be removed.

The final set-level model, was thus constructed as a logistic model with complementary log-log link:

(catch != 0) ~ offset(hook set) + s(soak time) + s(hbf) + s(sst, by = species) + hook category + bait + species

AIC (Akaike Information Criterion) values for the terms in the model are shown in Table 6. Plots of the final parameter estimates are shown in Figure 9. Since the workshop believed there was value in exploring the effect of hook category and bait type on interaction (catch) rates, a table of the absolute and relative increases in the probability of longline-sea turtle interactions under each combination for each species is included in *Annex F*.

Table 6. AIC values for the final set-level model adopted by the first workshop.

Model	**df**	**AIC**	**delta AIC**
Full model	30.8	11332.4	
- soak time	29.9	11335.5	3.1
- hook type	30.5	11457.1	124.7
- bait	35.6	11535.5	203.1
- hbf	31.2	11724.1	391.7
- sst:species	18.8	12316.1	983.7

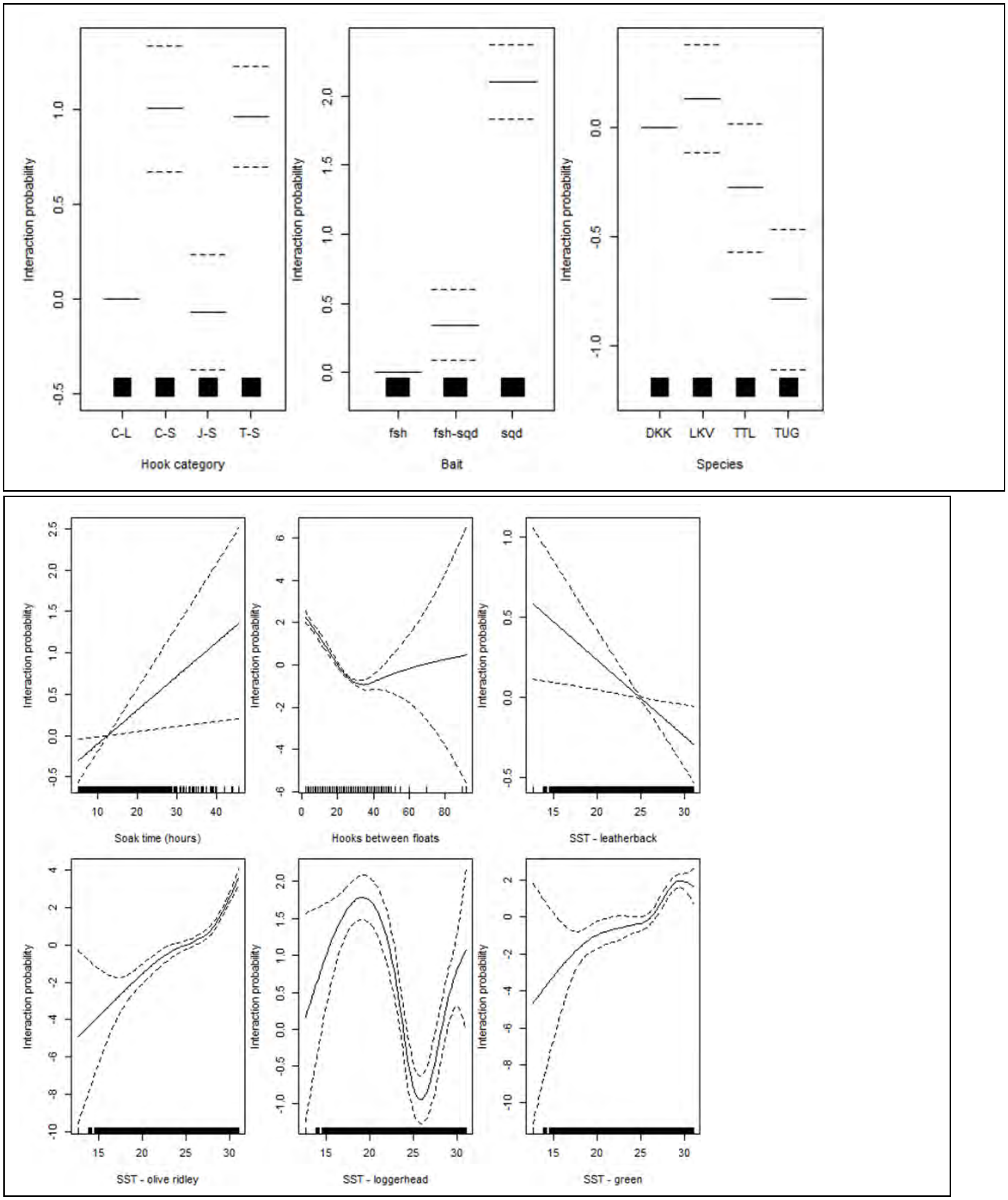


Figure 9. Plots of parameter estimates for the final set-level model for categorical explanatory variables (top panel) and continuous explanatory variables (bottom panel) in the first workshop. Set-level interaction probability (y-axis) was complementary log-log transformed, with larger y-axis values equivalent to higher interaction probabilities.

Noting that thus far the work on the set-level model had been limited to the presence/absence component, and the second step (i.e. estimating the number of turtles caught when the number of turtles caught is a positive number) is yet to be addressed, SPC noted that 90% of the turtles caught represent single catches (i.e. one turtle caught per set) and are thus represented in the presence/absence model. The maximum number of turtles for a given species per set was six. As an alternative to constructing a model for the n>1 catches, SPC suggested that the results of the presence/absence model be scaled to account for the relatively rare occurrences of multiple turtles caught in a given set. The workshop agreed that given time constraints this approach was acceptable (see Section 4.5.2 for more details on how this was accomplished).

4.1.2 *Activities between the First and Second Workshops*

In response to a number of issues raised in the first workshop, SPC investigated, prepared for, and in some cases undertook, additional analyses. However, lack of access to the full dataset due to confidentiality conditions on the Japan and Chinese Taipei data limited, in some cases, what could be accomplished.

There were a number of re-formulations of the dataset or the model raised in the first workshop that could not be undertaken there due to lack of time. These included:

- <u>Adjusting soak time for daylight</u> –an adjusted soak time variable was constructed, reflecting soak time during daylight hours, using 'local' sunrise and sunset times based on information on set time and location. This adjusted soak time variable would proposed to be used in place of the original soak time after testing in the second workshop.
- <u>Adjusting time of day of the set</u> – a categorical set time variable was constructed, reflecting the start time of setting relative to the position of the sun, with the following levels: day, night, dawn and dusk. This categorical variable was thus ready for testing for significance in the set-level interaction rate model in the second workshop.
- <u>Revising the format of the effort offset to account for the number of hooks per set</u> – the number of hooks set was included as an offset term in the first workshop. This forces a linear relationship between the linear predictor and hooks set. A non-linear relationship with hooks set may be more appropriate.
- <u>Revising the bait type categories</u> – the first workshop discussed that the mixed (squid/fish) bait type was not very informative because the proportions of squid and fish in this mixed category are unknown. SPC investigated this further but found that as only 26% of the observer records report the proportion of baits used (rather than simply listing the types), more informative bait type categories are not possible.
- <u>Substituting a measure of primary productivity for sea surface temperature</u> – Sea surface temperature was included in the model in the first workshop as an indicator of preferred habitat for each species. However, it is only one of many oceanographic variables that may be useful in identifying in which areas sea turtle interactions may be more likely. It was recommended that a measure of primary productivity, and a proxy for distance to shore, be included with/instead of sea surface temperature in the set-level model to determine if these variables can better predict interactions (see Section 5.1.1). Primary productivity, epipelagic forage, distance to shore and bathymetric depth were included in the dataset to allow this.

None of these changes could be made to the datasets, nor could the models be re-run outside of the workshop due to data confidentiality conditions. Therefore these changes were considered at the second workshop.

One exception to the hiatus of work with the actual data between the two workshops was model corrections undertaken in response to a data re-submission by Chinese Taipei in July 2016. Subsequent to the first workshop, Chinese Taipei conducted an in-depth review of the observer data they had contributed and verified some of the hook type information on the basis of interviews with fishing companies. The Chinese Taipei dataset was re-provided to SPC on 7 July 2016. The two data providers which allowed access to their observer data only in a workshop format, i.e. Japan and Chinese Taipei, agreed to allow SPC to run correction analyses using the new data in conjunction with their original datasets on 29 June 2016. SPC determined that only the set-level interaction rate model needed to be re-visited, as the models of hook-position interaction rate and condition at capture did not include hook type as an explanatory variable. SPC proposed and Chinese Taipei agreed that the best approach would be to re-run the set-level interaction rate model with the verified Chinese Taipei hook type data only (i.e. removing the unverified hook type data from the Chinese Taipei dataset). For the new model runs the specification of the model was not changed, only the hook type data with the modelled dataset.

In the revised set-level interaction rate model, the most important change in the results pertained to the estimation of the hook type effect on sea turtle interactions (Figure 10). The basis for this change was that some of the records previously classified as small J hooks (J-S) were identified as small Teracima and tuna hooks (T-S). Most notably, a significant difference between large circle hooks (C-L) and small J hooks (J-S) interaction rates became apparent, whereas there was no such difference in the previous results (compare the top left panels in Figures 9 and 10). In the revised results there were also no longer significant differences between small J hooks (J-S), small circle hooks (C-S) or small Teracima and tuna hooks (T-S), in other words all three of these hooks types now have similar interaction rates.

There were also some small changes in other parameters as a result of revision of the modelled dataset. This results from the fact that the new model fits to the new dataset differently. One example of this is that there is no longer a significant difference between fish and mixed fish-squid baiting regimes, whereas previously a mixture of fish and squid had intermediate interaction rates to fish alone and squid alone. There were other minor differences in the modelling results but these were not expected to have any meaningful impact on the relative performance of mitigation scenarios.

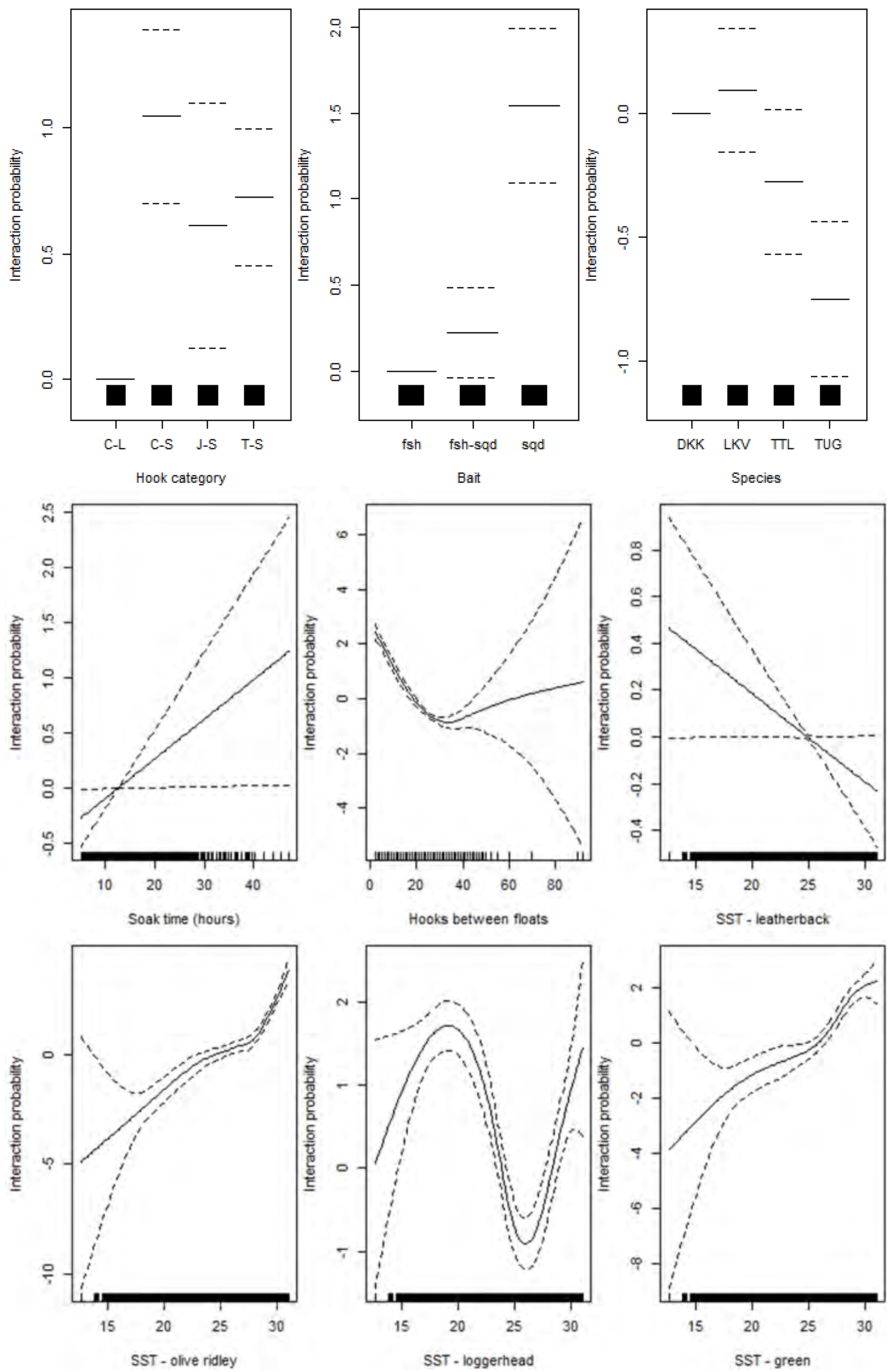


Figure 10. New effect plots of set-level model with verified Chinese Taipei hook type data (replacing those in Figure 9). Set-level interaction probability (y-axis) was complementary log-log transformed, with larger y-axis values equivalent to higher interaction probabilities.

4.1.3 *Second Workshop Outcomes*

During the second workshop SPC proposed to revisit the set-level model to assess the following revisions and modifications (see Section 4.1.2 for details):

- Revision of the soak time data field formulation;
- Revision of the time of day of set data field formulation;
- Using the number of hooks set as an explanatory variable instead of as an offset;
- Exploring whether adding net primary productivity and/or distance to land as explanatory variables would improve the fit of the model and/or serve as a proxy for sea turtle habitat preferences; and
- Refitting the model to the new dataset resulting from receipt of Japanese observer data from the Eastern Pacific Ocean.

Participants questioned whether extreme values of explanatory variables (e.g. soak time >40 hours and hbf>60) might be unduly influencing the models and thus should be removed from the dataset. SPC explained that as there are very few such data points their influence on the model would be negligible. Furthermore, as consistency checks did not reveal any clear evidence that these values are erroneous, it was decided to leave them in the dataset as they stand and simply note that future data quality checks should consider choosing a maximum reasonable value to use as a pre-model filter.

SPC examined the new formulation of time of day of set. Comparison of AIC values showed that the model was not improved with the addition of this variable.

SPC's information on the lack of proportions of bait types in the mixed fish/squid bait type was noted. As this lack of information precluded more precise analysis of bait type effects, participants suggested observer programmes should, in future, try to collect more detailed information on the proportions of different types of baits used. The suggestion was made to combine bait and hook types into joint categories, but it was pointed out that the first workshop had found that the dataset was unbalanced and would not support such variables, particularly in the case of a category comprised of large circle hooks and squid bait. The unbalanced nature of the data set was also the reason why a hook type*bait type interaction was dismissed in the first workshop. Combining hook type and bait type as a category might also reduce management flexibility (i.e. we would not be able to advise on the use of either mitigation measure separately even though previous studies suggest that either one of these mitigation measures worked as well as both measures implemented simultaneously).

The second workshop raised the potential for using fleet, EEZ or observer program as an explanatory variable in the set-level model. However, there are several reasons why these types of variables were not included. First, it is very likely that such categorical variables would be highly correlated with operational variables like hook type, bait type, hbf and soak time that are already included in the model. Second, this analysis is aimed at identifying factors which can be mitigated to reduce sea turtle interactions and mortalities and it is highly unlikely that mitigation measures would be specified for a particular fleet, EEZ or observer program.

There was then an extensive discussion of the potential use of additional habitat variables (e.g. net primary productivity, distance to land) in the set-level model. Noting the presentation by J. Bourjea showing that a model of juvenile leatherback distribution in the Pacific was parameterized using SST and net primary productivity (the latter as measure of the value of foraging habitat), the workshop discussed whether net primary productivity or another variable such as the SEAPODYM model's epipelagic foraging variable would be preferable. Given the potential differences between tuna and sea turtle forage, it was considered that net primary productivity might be the more appropriate variable. It was also considered that distance from land might be useful for some species such as green turtles. Since seamounts might serve as similar habitat to nearshore areas, it was agreed to formulate the distance to land variable as distance to the nearest 50 meter isobath.

SPC reported back on some of the new model results run without incorporating the new Japanese EPO data. Participants noted that although a variety of formulations of soak time were trialled, in none of the models was soak time more than marginally significant, and the model with the lowest AIC excluded the soak time explanatory variable altogether, suggesting it is unnecessary.

SPC noted that the inclusion of 'number of hooks fished' as an explanatory variable, rather than as an offset, is theoretically preferable and appears to have no effect on the estimated coefficients. Furthermore use of hooks set in the model can serve as a proxy for soak time since the time taken to deploy and retrieve a higher number of hooks would lead to a higher soak time. Workshop participants agreed that the soak time explanatory variable could be removed from the model.

With regard to the incorporation of new or alternative oceanographic variables, SPC compared models using only SST, only net primary productivity, and only distance to shore (i.e. distance to the nearest 50m isobath) using AIC values. The model with only SST had a considerably lower AIC value than the others and it was considered that the net primary productivity value was somewhat harder to interpret and predict for unobserved fisheries. Despite its higher AIC value, the model containing an explanatory variable for distance to shore was considered important for green and olive ridley turtles and so a model containing both SST and distance to shore was examined. The model including both SST and distance to shore was found to have a lower AIC lower than a model including SST only.

Concerns were expressed about the need to use the set-level model to predict interactions for known, but unobserved, effort in areas which are outside the range of either SST or distance to land values in the observed dataset. For distance to shore this was examined by plotting which areas are more than 1000 nmi beyond the 50m isobaths and it was noted that such areas occurred in the EPO from off California to Peru, and in an area between the South Island of New Zealand and southern Chile. SPC considered that including distance to shore in the model would improve the fit of the model to the WCPO data and though comparatively under-informed in the EPO, the higher uncertainty there would not pose a major impediment to the overall modelling exercise. It was also noted that the newly received Japanese EPO observer data will reduce the number of predictions that need to be made for distance to shore outside the range of observed values. SPC explained that only 0.18% of the effort required prediction outside the range of observed SST values, and participants considered that the model could be used for such predictions because even if the uncertainty for these predictions is high, their influence on the model would be minimal.

There were initially some issues encountered when modelling the Japanese EPO observer data which prevented the model from converging. However, whatever the cause of these issues convergence was achieved when soak time was dropped from the model, and thereafter the model performed well with only slight changes in estimated parameters. It was noted that both the Japanese WCPO and EPO observer data contained some sets which recorded use of circle hooks but as neither the size nor any other characteristics of these hooks were recorded, they were classified as hook type unknown and thus not used in the model.

The final set-level model consisted of

(catch != 0) ~ s(hbf) + s(hook set) + s(sst, by = species) + s(distance to shore, by = species) + hook category + bait + species

The final results of the condition model are shown in Table 7 and Figure 11and *Annex F*.

Table 7. AIC values for the final set-level model adopted by the second workshop.

Model	**df**	**AIC**	**delta AIC**
Full model	53.0	10132.7	
- hook category	50.9	10150.8	18.1
- hook set	50.5	10160.2	27.4
- bait	49.6	10166.1	33.4
- distance:species	36.0	10286.1	153.4
- hbf	52.9	10327.9	195.2
- sst:species	36.5	10595.6	462.9

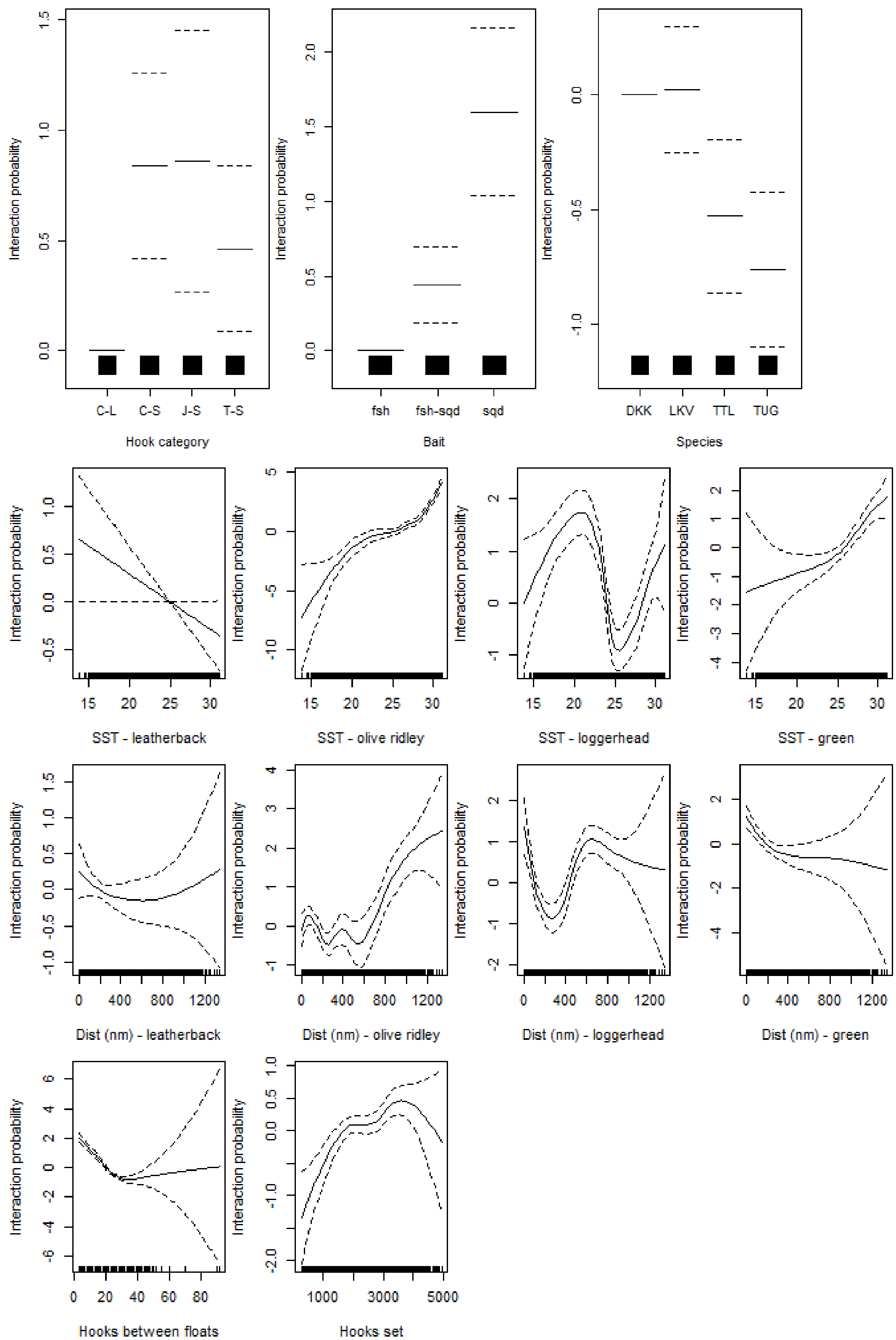


Figure 11. Effect plots for the final set-level model adopted by the second workshop (replacing those in Figure 10). Set-level interaction probability (y-axis) was complementary log-log transformed, with larger y-axis values equivalent to higher interaction probabilities. Dist (nm) refers to distance to the nearest 50 m isobath.

4.2 Modelling Longline-Sea Turtle Interactions by Hook Position (Hook Position Model)

4.2.1 *First Workshop Outcomes*

SPC explained that this model is useful to specifically address potential mitigation techniques associated with removing the shallowest hooks closest to the float. The model was constructed to estimate the probability of encountering a turtle at a given hook position and was applied only to sets in which at least one turtle was caught. Deep and shallow fisheries were modelled separately to account for the fact that the same hook position in shallow versus deep sets would actually fish at different depths.

SPC suggested and workshop participants agreed the following list of explanatory variables for an initial modelling run:

- **Hook Position** –the hook number as counted from the nearest float (with shark lines assigned a hook number of zero) and is the key variable of interest for this model
- **Hooks between floats** (hbf) **–** this was considered necessary to account for the variable depth at which a hook of a given position would fish
- **Floatline length –** like hbf this was also considered necessary to account for the variable depth at which a hook of a given position would fish
- **Species –** to account for differing interaction rates by species

An interaction between species and SST was included to account for species-specific habitat preferences where habitat is represented by SST. An additional interaction term was included for hook position and species to account for species-specific depth preferences.

Results of the initial modelling run suggested that in the deep set model there is declining catch with increasing hook position, with the exception of leatherback turtles which are found at a wide range of depths and have a higher propensity to be entangled rather than hooked. In the shallow set model there was no significant difference between turtle catches on hooks 1-4 but there was a significantly lower catch of turtles on shark lines (hook position zero).

Participants discussed whether it is important to retain the interaction between SST and species if it is not significant for leatherback turtles. SPC explained that overall the SST-species interaction term is significant even though it is not significant for leatherbacks. Participants speculated as to why this is the case but there was no ready explanation.

With regard to shark lines in particular, SPC noted that the deep set model is not well-formulated to test the extent to which shark lines affect turtle catches and thus an alternative model would be needed for this purpose. Further consideration of including shark lines in the model would require that the unbalanced nature of shark lines and branchlines be addressed.

Two additional ideas were raised for this model: i) include the presence or absence of a line shooter as an explanatory variable (most important for deep sets); and ii) run the model again for a subset of data that does not contain any mixed fish-squid bait so that if there is any confounding influence of bait on the model result this is minimized. The first idea could not be explored due to lack of data on whether a line shooter was used. For the second idea, when the model was run on the suggested subset of data the hook position effect did not change from the full model which indicates that bait is not a confounding factor. Some participants, noting that the observers' workload is heavy and their recording of hook position information is thus somewhat unreliable, cautioned against placing a heavy emphasis on hook-specific information.

The hook position models for the first workshop were thus constructed as logistic models with a complementary log-log link:

Deep model
(catch != 0) ~ s(hook position, by = species) + s(float length) + s(hbf) + species+ s(sst, by = species)

Shallow model
(catch != 0) ~ as.factor(hook position) + s(float length) + s(hbf) + species + s(sst, by = species)

The hook position and species interaction term did not improve the shallow set model based on AIC, and so was not included in the final model.

AIC values for the terms in the model are shown in Table 8. Plots of the final parameter estimates are shown in Figure 12.

Table 8. AIC values for the final hook position model for deep and shallow sets adopted by the first workshop.

Deep Model	**df**	**AIC**	**delta AIC**
Full model	28.0	4501.9	
- float length	26.3	4506.3	4.4
- hbf	26.9	4507.9	6.0
- sst:species	14.1	4533.5	31.5
- hook position:species	20.4	4611.3	109.4

Shallow Model	**df**	**AIC**	**delta AIC**
Full model	28.1	3545.1	
- float length	27.1	3544.0	-1.1
- hbf	27.8	3550.1	5.0
- hook position	34.9	3572.7	27.6
- sst:species	11.0	4176.5	631.4

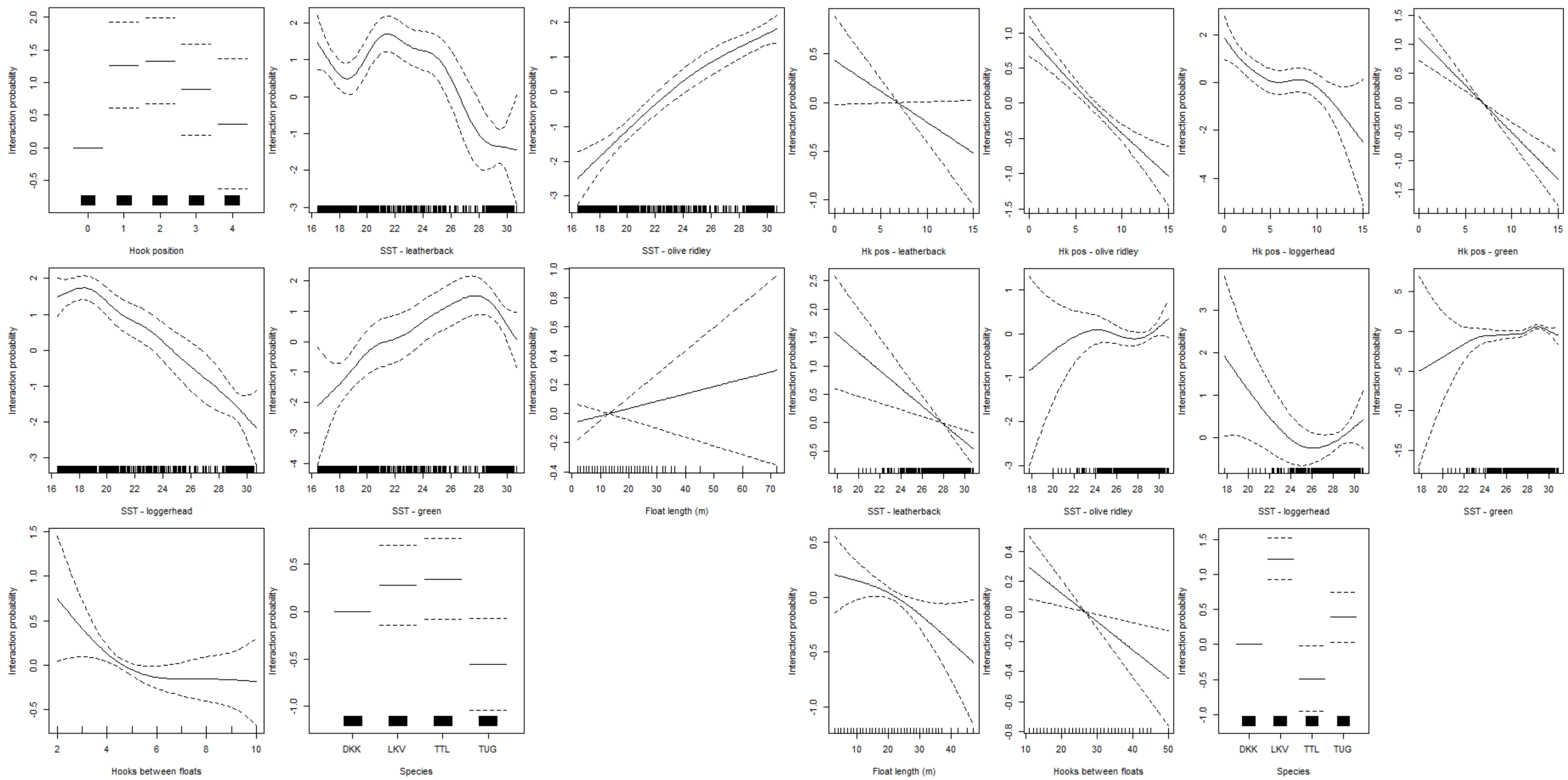


Figure 12. Plots of parameter estimates for the hook position model adopted by the first workshop. Results for the shallow model are shown in the left panel with deep model results in the right panel. Hook position (hk pos) interaction probability (y-axis) was complementary log-log transformed, with larger y-axis values equivalent to higher interaction probabilities. The modelled datasets included records for shark lines (hook position = 0) where appropriate. However, robust estimation of interaction rates for shark lines was prevented by the unbalanced nature of the dataset, and thus shark lines were not considered in the simulation model.

A table showing the percent differences in turtle interactions by hook position was constructed and is shown as Table 9.

Table 9. Percent differences in turtle interactions by hook position according to the final version of the hook position model adopted by the first workshop. The interaction probability is provided for the first hook position closest to the float and shown as percentage change (from the first hook position closest to the float) for the other hook positions. The deep model results are shown above with the shallow model results below.

Deep	Hook Position							
Species	**1**	**3**	**5**	**7**	**9**	**11**	**13**	**15**
DKK	0.013	-12%	-17%	-22%	-27%	-31%	-36%	-39%
LKV	0.065	-24%	-34%	-43%	-50%	-56%	-62%	-66%
TTL	0.022	-54%	-66%	-75%	-77%	-72%	-65%	-66%
TUG	0.052	-27%	-38%	-47%	-55%	-61%	-67%	-72%

Shallow	Hook Position				
Species	**0**	**1**	**2**	**3**	**4**
DKK	-70%	0.147	6%	-29%	-58%
LKV	-71%	0.078	6%	-30%	-58%
TTL	-71%	0.078	6%	-30%	-58%
TUG	-71%	0.049	7%	-31%	-59%

4.2.2 *Activities between the First and Second Workshops*

As described in Section 4.1.2, SPC made preparations to enhance the data and the models between the two workshops but due to data confidentiality conditions did not re-run the hook position model. The key modification for this model involved reformulating it to remove the habitat suitability term (i.e. remove the SST term). The SST term was required at the first workshop because the modelled dataset included hook-position specific interaction rates for all sets where at least one turtle was caught. The SST term (and any other environmental variables) are not required if records are only included for a given turtle species when at least one turtle of that species was caught on the set in question. This approach simplifies the hook position model without compromising its predictive capability, and is therefore recommended.

In addition to these changes to the model and data formulation, the hook position model needed to be re-run for the new dataset which now includes data from Japan for the Eastern Pacific Ocean.

4.2.3 *Second Workshop Outcomes*

The workshop agreed with SPC's proposed revision as outlined above. The hook position model was re-run with the new dataset (including the Japan EPO data) and the results appeared unchanged under the new, simpler model structure. However, there was no longer any compelling support in the data for inclusion of the floatline length (deep and shallow models) and species (shallow model only) terms and thus these were removed from the model.

SPC clarified that hook position zero, which would correspond to a hook hung off the float itself (e.g. a shark line) is not used in the model even though it is shown in the results plots. Participants thus suggested that hook position zero be suppressed in the plot to avoid confusion.

The final formulation of the hook position model is shown below with the model results given in Tables 10 and 11 and Figure 13.

Deep model
(catch != 0) ~ s(hook position, by = species) + s(hbf) + species

Shallow model
(catch != 0) ~ as.factor(hook position) + s(hbf)

Table 10. Percent differences in turtle interactions by hook position according to the final version of the hook position model adopted by the second workshop. The interaction probability is provided for the first hook position closest to the float and shown as percentage change (from the first hook position closest to the float) for the other hook positions. The deep model results are shown above with the shallow model results below.

Deep	**Hook Position**								
Species	**1**	**2**	**3**	**5**	**7**	**9**	**11**	**13**	**15**
DKK	0.115	-8%	-15%	-28%	-38%	-48%	-56%	-62%	-68%
LKV	0.168	-14%	-27%	-46%	-60%	-68%	-74%	-79%	-83%
TTL	0.207	-38%	-56%	-74%	-71%	-65%	-79%	-93%	-98%
TUG	0.171	-14%	-27%	-47%	-61%	-72%	-80%	-86%	-90%

Shallow	**Hook position**			
Species	**1**	**2**	**3**	**4**
All species	0.310	7%	-29%	-56%

Table 11. AIC values for the final deep and shallow hook position model adopted by the second workshop.

Deep Model

Model	**df**	**AIC**	**delta AIC**
Full model	15.7	3161.8	
- hbf	14.8	3183.8	22.0
- hook position:species	7.1	3276.1	114.3

Shallow Model

Model	**df**	**AIC**	**delta AIC**
Full model	7.5	2136.9	
- hbf	5.0	2149.2	12.3
- hook position	3.5	2185.3	48.4

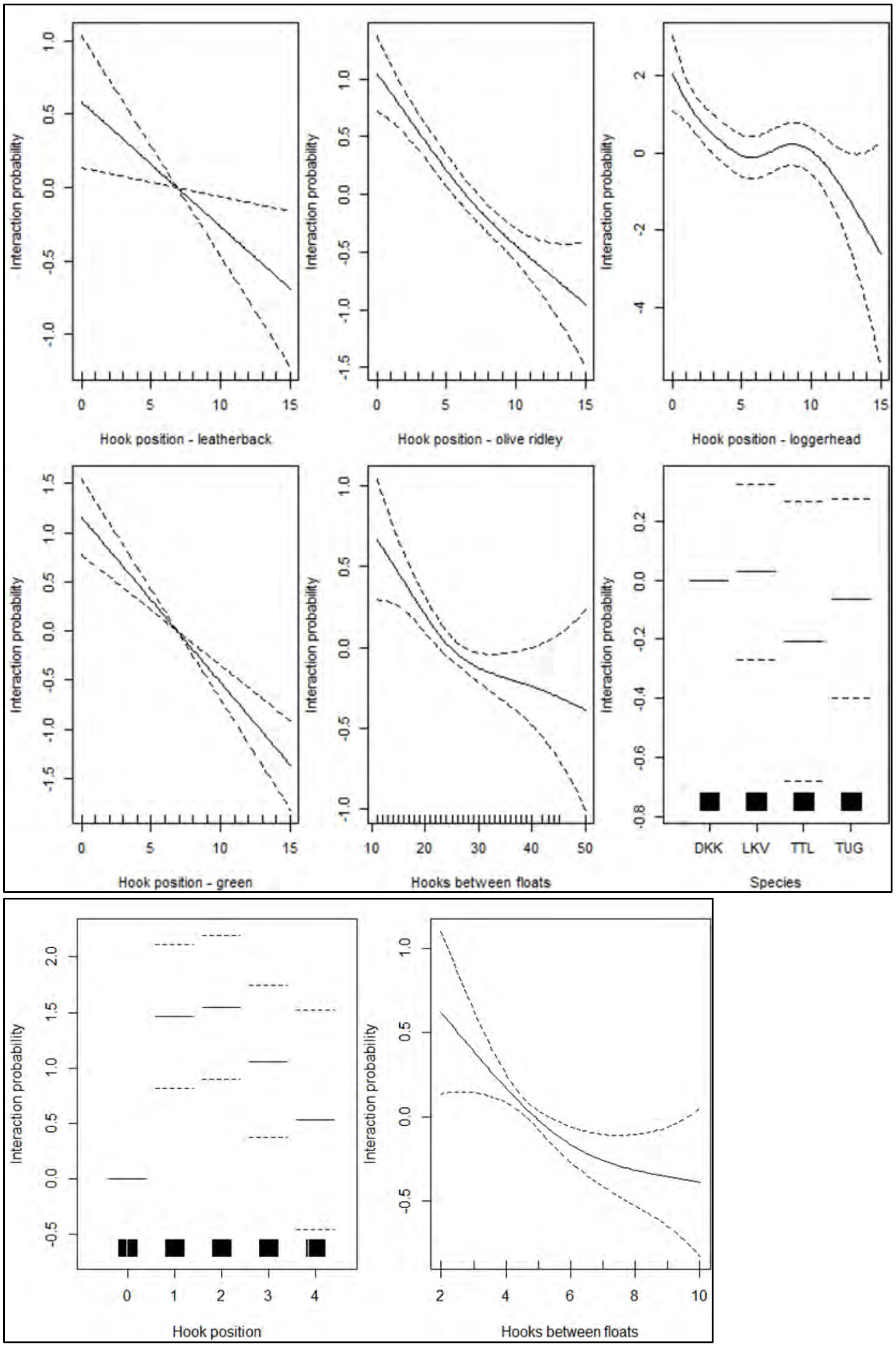


Figure 13. Effect plots for the final hook position model adopted by the second workshop (replacing those in Figure 12). Results for the deep model are shown in the top panel with shallow model results in the bottom panel. Hook position interaction probability (y-axis) was complementary log-log transformed, with larger y-axis values equivalent to higher interaction probabilities. The modelled datasets included records for shark lines (hook position = 0) where appropriate. However, robust estimation of interaction rates for shark lines was prevented by the unbalanced nature of the dataset, and thus shark lines were not considered in the simulation model.

4.3 Modelling Longline Sea Turtle Condition (Condition Model)

4.3.1 *First Workshop Outcomes*

SPC presented some preliminary information on the structure of the condition model and the data available to inform it. Condition at the point of first sighting by the observer (at-vessel) is recorded for ~ 80% of the turtles in the observer data. A binary category (alive/dead) was proposed, with all turtles seemingly alive classified as alive (even if coded as "alive, unlikely to live"). The proportion alive decreases with increasing soak time for shallow sets. Potential explanatory variables which have good coverage in the dataset were considered to be bait type, floatline length, branchline length, soak time and time of day of set. Less information is available for hook type, lightsticks and wire trace, and even less information for other variables. In deep sets 39% of turtles were recorded as alive at first observation, whereas in shallow sets 93% were recorded as alive at first observation.

Participants agreed that turtles should be considered alive if classified by the observer as alive in any way. Participants reflected on variables considered *a priori* to affect condition along with the availability of information for each data field and identified the following variables for an initial run:

- **Species** – variable conditions (alive/dead at retrieval) by species could be attributed to such factors as differing body sizes, metabolic rates, lung capacities, swimming ability or life stages likely to be encountered by longline fisheries as well as the fact that some species occur shallower and are less likely to asphyxiate on shallow hooks;
- **Hooks between floats (hbf)** – it is recognized this is an attempt to account for hook depth but will be inherently uncertain;
- **Time of day of set** – it was noted that the same time of day of set could represent variable times before or after dawn or dusk based on season and latitude therefore times should be adjusted if possible to account for this (see discussion above);
- **Soak time** – preliminary analysis suggests a relationship between soak time and survival but this may reflect some underlying conditions such as longer night soak times having more chance of daylight at the end of the soak and thus catching "fresh" turtles which are able to survive. (More work should be done to explore this factor in relation to set time.)
- **Length of the floatline** – in theory longer floatlines may be more likely to cause entanglement or be more likely to be fished at hook depths that lead to asphyxiation.

It was acknowledged that there may be interactions between some of these variables which could be explored. However, given the decision for the set-level model not to estimate interactions for which data are insufficient to support robust estimation, it was decided not to include any interaction terms other than those involving species in the condition model.

Two other explanatory variables were suggested. The first was anatomical hooking location, but this was considered unlikely to be possible to explore given insufficient information in the current datasets. The second variable was the size of weights on the branchline which was suggested on the basis that the heavier the gear, the less likely a caught turtle would be able to reach the surface to breathe during the soak. This variable also suffers from insufficient data and cannot be explored.

Initial results from the preliminary model showed that according to the AIC values all of the explanatory variables should be retained in the model. However, the variables with the greatest influence on the results were hooks between floats and species, with a lesser influence from soak time and float length. Participants noted that some of these variables may be proxies for a shallow-set strategy, for example, setting later in the day is common in swordfish fisheries which catch target species at night.

The condition model, was thus constructed as a logistic model with a logit link:

response ~ s(soak time) + s(set time) + s(float length) + s(hbf) + species

AIC values for the terms in the model are shown in Table 12. Plots of the final parameter estimates are shown in Figure 14.

Table 12. AIC values for the final condition model adopted by the first workshop.

Model	**df**	**AIC**	**delta AIC**
Full model	20.34	893.1	
- set time	19.38	901.2	8.2
- soak time	15.66	903.5	10.4
- float length	18.14	909.1	16.1
- hbf	26.11	990.6	97.5
- species	19.46	1034.2	141.1

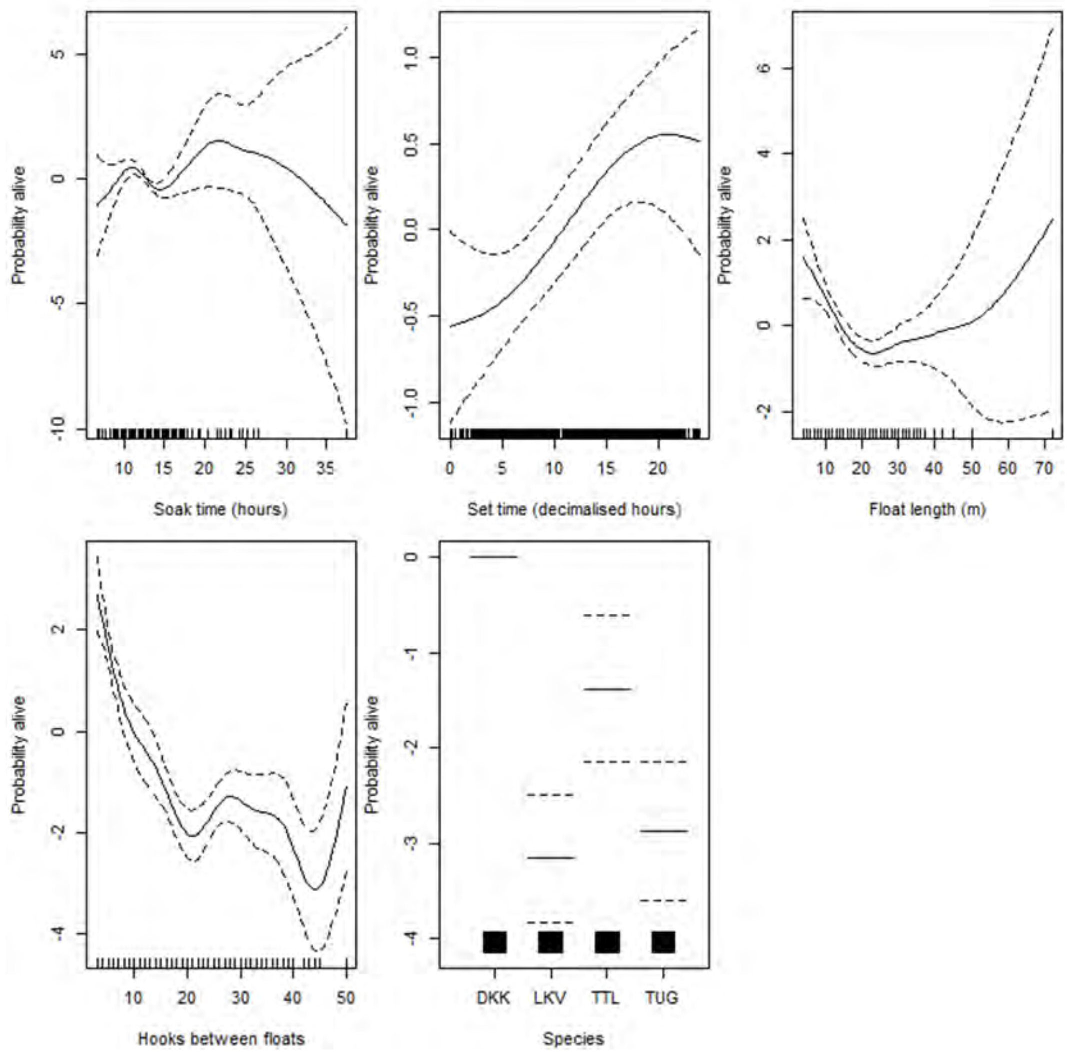


Figure 14. Plots of parameter estimates for the final condition model adopted by the first workshop. At-vessel catch condition probability (y-axis) was logit transformed, with larger y-axis values equivalent to higher probabilities of being alive at-vessel.

4.3.2 *Activities between the First and Second Workshops*

As described in Section 4.1.2, SPC made preparations to enhance the data and the models between the two workshops but due to data confidentiality conditions did not re-run the condition model. One change to the model was proposed for consideration in additional model runs: the categorical set time variable described in Section 4.1.2 could replace the decimal set time variable. It was considered that although, like the set-level model, soak time appears in the condition model, a revised formulation of the soak time variable is not required here because the relationship between soak time and condition is expected to be invariate to time of day.

4.3.3 *Second Workshop Outcomes*

Participants suggested that rather than adjusting the set time variable as proposed by SPC, the variable could simply be dropped from the model as it is not likely to influence whether a hooked sea turtle survives until being hauled to the vessel. Participants agreed with SPC that the soak time variable need not be adjusted for daylight since whether a turtle survives does not depend on daylight. When SPC re-ran the model without the set time variable the results were nearly identical to those presented in the first workshop, suggesting that the variable could be dropped as proposed.

Participants also considered whether a variable reflecting branchline length, or the ratio of branchline to floatline length (i.e. whichever is longer), should be included in the condition model. In particular, it was noted that as floatline length increased the chance of a hooked turtle surviving would decrease as the hooks would tend to be deeper with a higher likelihood that the sea turtle could not reach the surface for respiration. However, if branchline length also increased, reaching the surface might still be possible depending, potentially, on hook position, propensity for tangling, etc.

SPC reported back with some preliminary results run on the entire dataset (i.e. including the new Japanese EPO observer data). Among models consisting of:

- no branchline length explanatory variable;
- inclusion of a branchline length explanatory variable;
- inclusion of an explanatory variable consisting of the ratio of branchline to floatline length; and
- inclusion of explanatory variables for branchline length, floatline length and an interaction between branchline length and floatline length;

the fourth model was shown to have the lowest AIC value. However, further examination of the interaction term showed that it is difficult to interpret and may not add much explanatory power to the model. Therefore the workshop agreed it was preferable to include branchline length and floatline length as single factors and dispense with the interaction term.

Some participants considered that hook type and bait type should be considered for inclusion in the condition model. Other participants suggested that while hook type and bait type might influence anatomical hooking location, mortality would be likely to occur after haulback and release and thus not be recorded by observers. Some participants suggested that SST also be investigated as an explanatory variable for the condition model on the grounds that temperature has a large effect on stress. SPC explored the potential of hooks to affect at-vessel mortality using hook shape instead of hook type (i.e. shape and size) because there are a greater number of records containing hook shape and thus greater statistical power to detect significant effects. Also, from published research, hook shape seems consistently related to anatomical hooking location regardless of hook size. With such a model all three new variables (i.e. hook shape, bait type and SST) were significant, and the AIC was lower than the previous model, but the soak time variable was not significant in this new model. SST was found to explain more of the variance than hook shape or bait type and the relationship was such that lower SST explained lower mortality and higher SST explained higher mortality. Participants considered that bait type, while statistically significant was not likely to predict mortality and might be correlated with the depth of set (i.e. targeting strategy). Thus it was agreed to drop bait type from the model. When doing so SPC noted that branchline length became non-significant so this explanatory variable was also dropped. Hook shape was retained in the model because it was considered that it might determine long-term (i.e. post release) mortality, and there might be a relationship between short-term (at-vessel, i.e. what is being modelled in the condition model) and long-term mortality.

Another issue arose when incorporating SST into the condition model, i.e. spatial variation in catch condition for a given gear configuration as a result of variation in SST. The simulation model was coded without the capacity to include spatial variation in catch condition, reflecting the condition model structure agreed at the first workshop. Unfortunately, the re-coding required to circumvent this issue would have taken more time than available within the workshop. Furthermore, it is likely that the computational resources available at the workshop would have been insufficient to run simulations in a timely manner. As a work-around, SPC proposed to calculate the effort-weighted average SST for each fleet and target strategy (130 such fleet-target strategy combinations), using Reynolds SST data at a 1 degree square and monthly resolution and input this to the condition model as SST values. Participants expressed some concern about this approach because it would not capture the true variation in SST for each fleet. In contrast, some participants suggested that since vessels often attempt to follow isotherms it may not be unrealistic to assume a stable temperature profile by fleet and target strategy. In order to test whether such an approach would produce an effect consistent with that predicted by the condition model it was suggested that SPC use the effort-weighted, fleet-target average SST variable in a sensitivity test of the condition model to see if these less-resolved temperatures would show a similar effect on condition. SPC merged the effort-weighted SST values into the observer dataset based on each observed set's fleet and target strategy and re-ran the condition model to determine if the fit of the data to the model changed. The results of this test indicated that the relationship between SST and mortality was still statistically significant and similar in shape when using the merged dataset. On this basis participants agreed that including an average SST by fleet-targeting strategy was a useful approximation given the practical time and computing power constraints.

The final condition model, consisted of a logistic model with a logit link:

response ~ s(soak) + s(float.length) + s(hbf) + s(sst) + species + hook shape

where the response variable represents alive (if true) and dead (if false).

The final results of the condition model are shown in Table 13 and Figure 15.

Table 13. AIC values for the final condition model adopted by the second workshop (replacing Table 9).

Model	df	AIC	delta AIC
Full model	20.2	625.2	
- soak	17.7	625.6	0.4
- hook shape	15.6	627.8	2.5
- float line length	16.6	628.9	3.7
- sst	21.0	647.8	22.6
- species	17.6	687.5	62.3
- hbf	18.0	782.1	156.9

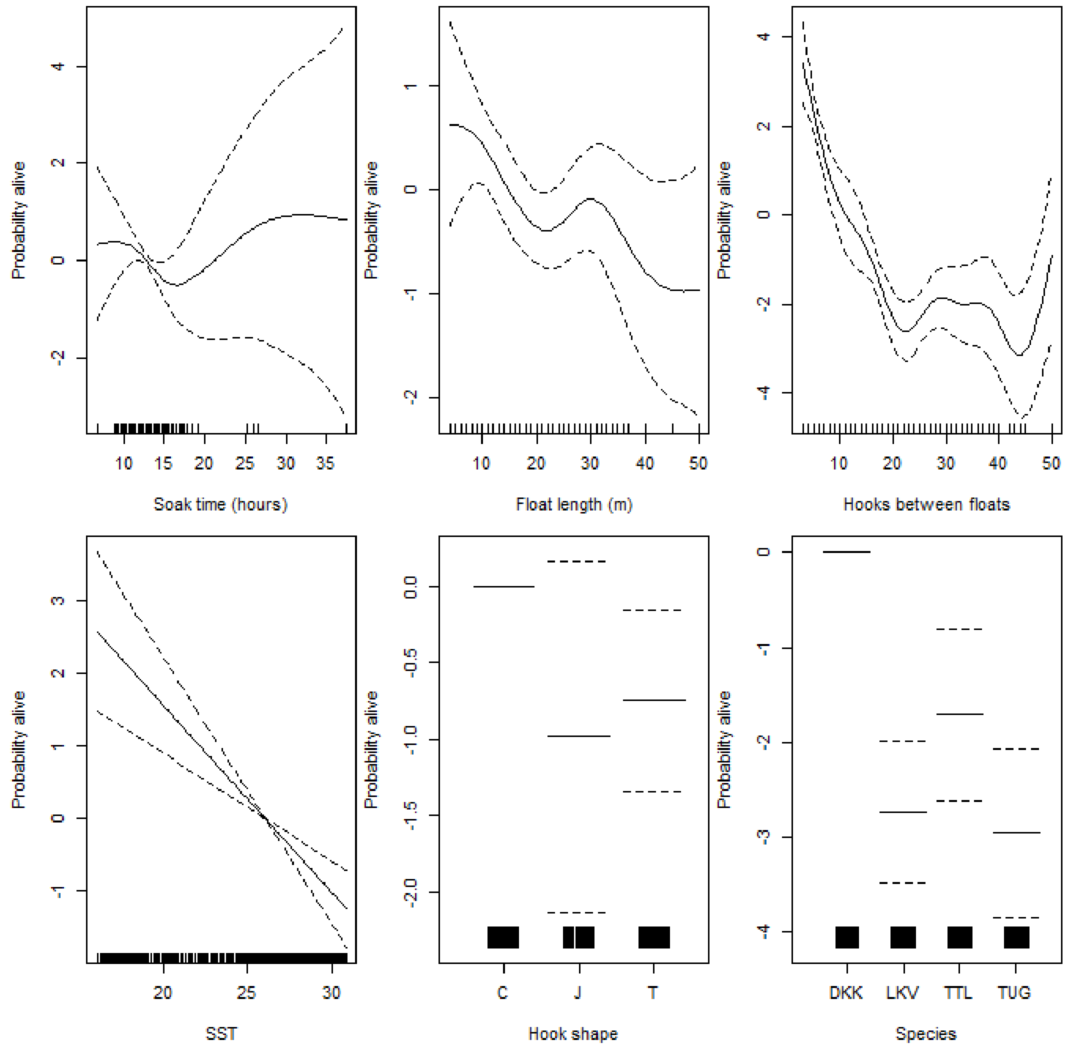


Figure 15. Effect plots for the final condition model adopted by the second workshop (replacing those in Figure 14). At-vessel catch condition probability (y-axis) was logit transformed, with larger y-axis values equivalent to higher probabilities of being alive at-vessel.

4.4 Integrating Information on Sea Turtle Relative Abundance

4.4.1 *First Workshop Outcomes*

In recognizing that the abundance of turtles varies in time and space in ways that cannot easily be quantified in the models envisaged for this analysis, the workshop was asked to consider the basic relative abundance maps used in the shark analysis (SPC 2015) to see if something similar could be constructed for turtles. A relative abundance surface is important for the simulation model in order to approximate the spatial distribution of turtles and adjust fishing effort to reflect this distribution. Some participants considered that maps of regional management units (RMUs; Wallace et al. 2011) used by the State of the World's Sea Turtles (SWOT[5], OBIS-SEAMAP; Halpin et al. 2009) project could provide a good starting point. This information included the boundaries of regional management units, distribution data, location of nesting sites and number of females at each nesting site. Other participants expressed concern about relying too heavily on these maps given that they do not correspond well with the patterns in which turtles are caught in fisheries, have little or no information on seasonal abundance or densities (by life stage and sex) within the Regional Management Units, and do not cover all areas where turtles are caught (Sales et al. 2015).

In order to produce a first spatialized estimated relative abundance by species, SPC with input from workshop participants, used global distribution maps from SWOT for each species to define a "presence" area (i.e. all areas outside the "presence" area were given a weighting of zero). They then weighted each identified RMU within the "presence" area by using the abundance of nesters estimated by SWOT in each nesting site known for each RMU and that seemed to the workshop participants to be representative of the current number of nesting females. Where RMUs overlapped, the sum of the weights of each of the two overlapping RMUs were assigned to the overlap area.

In order to investigate if RMUs were representative of the abundance, SPC overlaid RMUs and turtle bycatch positions available from purse seine and longline fisheries dataset available to the workshop for each species. Results showed that a good correlation exists between these sources, but also highlighted that some key areas of abundance may not be captured by RMUs, suggesting that some RMU boundaries may need to be revised in order to be representative of regional abundances. The absence of data from the EPO might skew the results, particularly when populations are believed to extend across the width of the Pacific. However, given that the estimation only covers the WCPO, this bias is less of a concern. The workshop agreed that it would be useful to further refine the maps by adjusting the RMUs after review of updated data including the presence/absence plots from this workshop and other available data sets not used to define RMUs. However, as this is likely to be a time-consuming task, it was agreed not to adjust any of the RMU boundaries at this workshop. Obtaining further expert input on the maps was proposed as a priority activity.

For areas outside RMUs but still within the species distribution area, a weight equivalent to half of the lowest total number of nesters for a given species per RMU was arbitrarily applied to reflect the presence of sea turtles. This exercise was repeated for the four species considered in the workshop (leatherbacks, loggerheads, olive ridley and green turtles) and a 5-degree grid with the associated weights was generated for each species to provide a relative abundance surface. In subsequent

[5] Kot, C.Y., E. Fujioka, A.D. DiMatteo, B.P. Wallace, B.J. Hutchinson, J. Cleary, P.N. Halpin and R.B. Mast. 2015. The State of the World's Sea Turtles Online Database: Data provided by the SWOT Team and hosted on OBIS-SEAMAP. Oceanic Society, Conservation International, IUCN Marine Turtle Specialist Group (MTSG), and Marine Geospatial Ecology Lab, Duke University. http://seamap.env.duke.edu/swot.

discussion it was considered that it is appropriate to adjust the weighting based on the number of nesting females as described above by the size of each colored shape on the map. The maps were prepared so that legends show this weighting scale. Participants also asked for a table showing the area of each colored shape on the map as a proportion of the WCPFC Convention Area (*Annex G*).

In discussing the map products prepared by SPC participants noted that all areas within an RMU are assigned the same weight and thus the effect of gyres and other oceanographic features which are likely to be important for turtle distributions are discounted. This may be an insurmountable issue for now as there are currently no reliable models to predict turtle presence for most species.

Participants discussed whether the fishery data should be given more weight in the maps. Some participants considered that fishery interactions are already accounted for in the set-level model and should be applied in the turtle relative abundance surface only as a kind of check. It was further noted that these data do not reflect the underlying effort in each area and thus can be misleading as locations where there was effort but no interaction are not shown. In contrast, some participants considered that fishery data should be weighted more heavily and could be modelled to produce a heat map style grid similar to the shark analysis (Harley et al. 2015).

Overall participants stressed that there are numerous substantial uncertainties associated with the maps produced but they represent the best information available to the workshop with regard to a relative abundance surface for turtles (Figures 16-23). Participants recommended that further work on the maps should be undertaken including an update of the information underlying the SWOT dataset, the use of environmental data such as SST, primary production and gyre areas, review by experts, and access to other fishery datasets to map the geographic scope of interactions.

4.4.1 *Activities between the First and Second Workshops*

One of the recommendations from the first WCPFC workshop on sea turtle bycatch mitigation was to peer review the relative abundance maps intended for use in the simulation models (Section 4.4.1). As detailed relative abundance data are not available on a Pacific Ocean wide scale, a formal expert review process of the maps derived at the first workshop was carried out in the form of an online Delphi survey. The Delphi survey provided a structured approach for gathering expert information in an iterative (round-based) framework, designed to foster consensus. In the first round, experts submitted an answer, and were then asked to review either a summary or complete answers from other experts. Experts could then alter or retain their responses in the second round, based on the information from the first round.

The Delphi survey, conducted by Dragonfly Data Science, allowed participants to submit relative abundance maps for each of the four sea turtle species. It was implemented in a web application that allowed experts to log-in, from an invitation e-mail, to access maps that could be “coloured in” to categorize large areas across the Pacific Ocean, based on predefined relative abundance categories. These categories were:

- Absence (<1% of maximum density);
- Low density (1-33% of maximum density);
- Medium density (34-66% of maximum density);
- High density (67-99% of maximum density); and
- Maximum density.

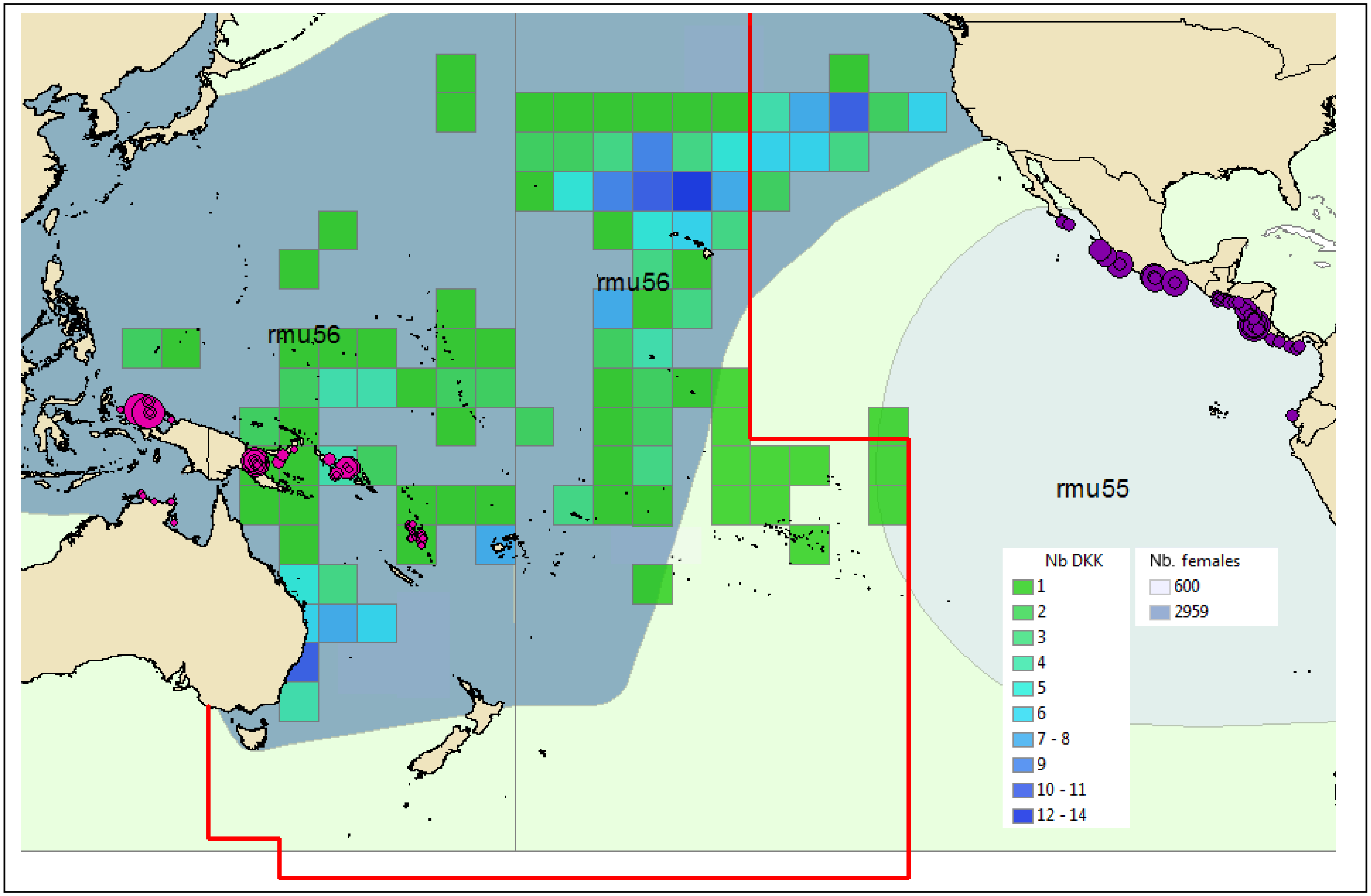


Figure 16. Input information for the relative abundance surface for leatherback sea turtle (*Dermochelys coriacea*, DKK) from the first workshop. The shaded areas are taken from the SWOT and represent RMU boundaries for the Pacific Ocean. Blue shading indicates relative abundance of nesting females (the number of females is estimated). Circles ranging in color from pink to blue indicate nesting sites. The total number of turtle interactions recorded by observers on purse seine and longline vessels is shown in 5x5 grids. Red lines indicate the WCPF Convention Area boundary. Note: When including this figure from the first workshop report in the final workshop report, it was noticed that no purse seine data were included (thus only longline data are shown), and only the color scheme for plotting was modified.

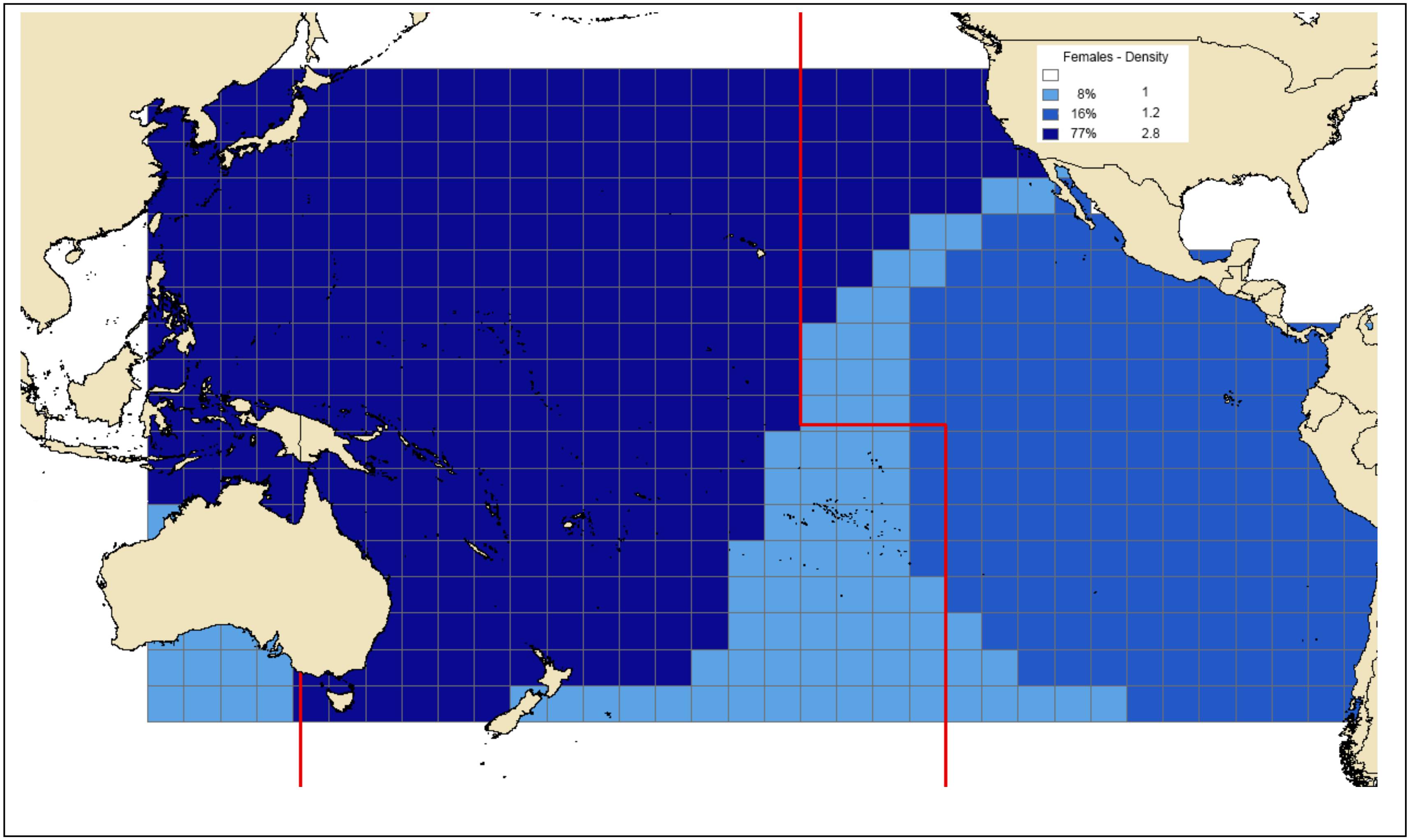


Figure 17. Relative abundance surface for leatherback sea turtle (*Dermochelys coriacea*) from the first workshop. The shading represents the relative abundance surface (blue areas from the preceding figure) weighted by the number of nesting females in each area (from the preceding figure) with the weighting categories listed as “density” in the legend. "Females" in the legend indicates the percentage of estimated nesting females per area. Where shown, white areas represent areas outside the global distribution of the species. Red lines indicate the WCPF Convention Area boundary.

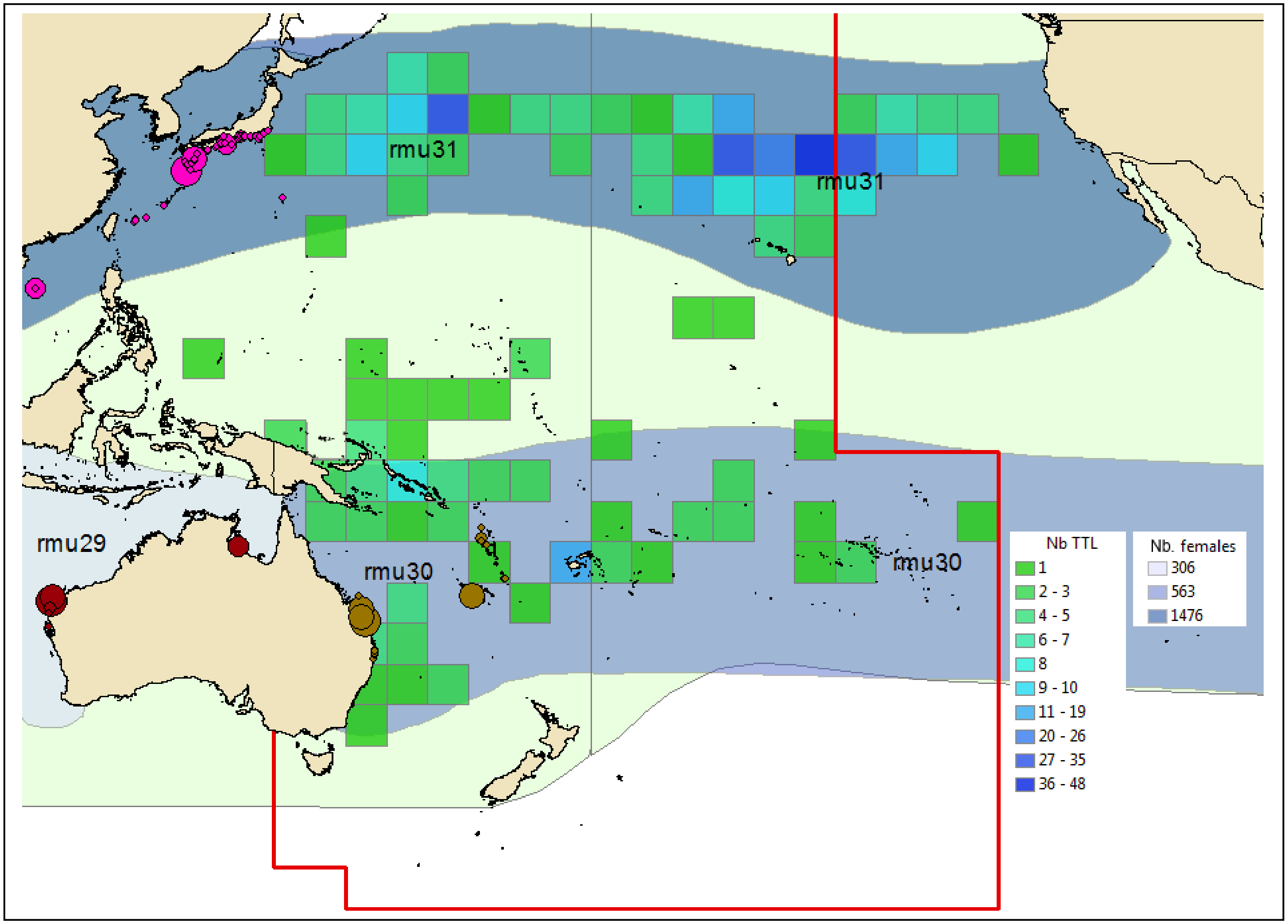


Figure 18. Input information for the relative abundance surface for loggerhead sea turtle (*Caretta caretta*, TTL) from the first workshop. The shaded areas are taken from the SWOT and represent RMU boundaries for the Pacific Ocean. Blue shading indicates relative abundance of nesting females (the number of females is estimated). Circles ranging in color from pink to blue indicate nesting sites. The total number of turtle interactions recorded by observers on purse seine and longline vessels is shown in 5x5 grids. Red lines indicate the WCPF Convention Area boundary. Note: When including this figure from the first workshop report in the final workshop report, it was noticed that no purse seine data were included (thus only longline data are shown), and only the color scheme for plotting was modified.

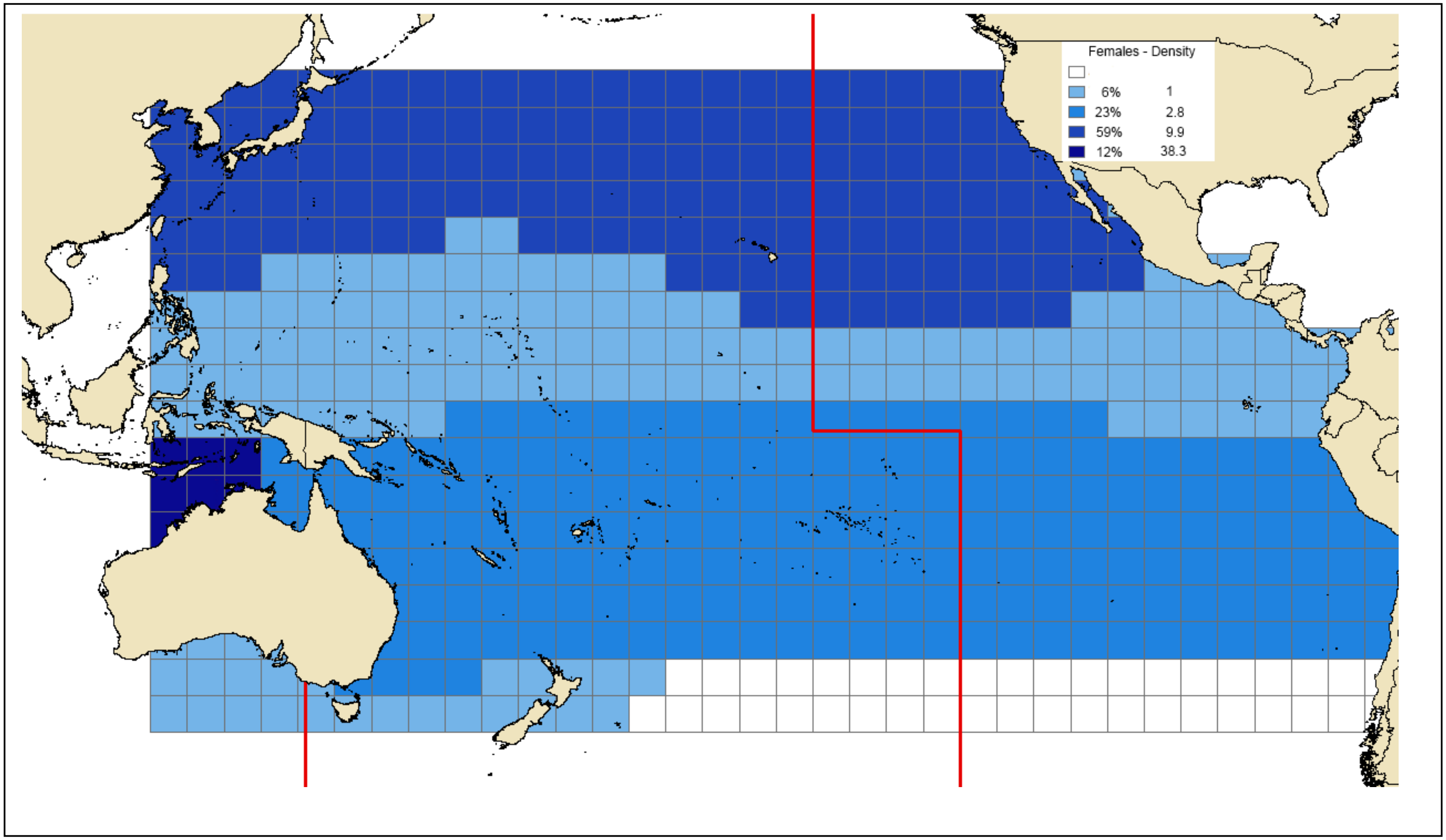


Figure 19. Relative abundance surface for loggerhead sea turtle (*Caretta caretta*) from the first workshop. The shading represents the relative abundance surface (blue areas from the preceding figure) weighted by the number of nesting females in each area (from the preceding figure) with the weighting categories listed as “density” in the legend. "Females" in the legend indicates the percentage of estimated nesting females per area. Where shown, white areas represent areas outside the global distribution of the species. Red lines indicate the WCPF Convention Area boundary.

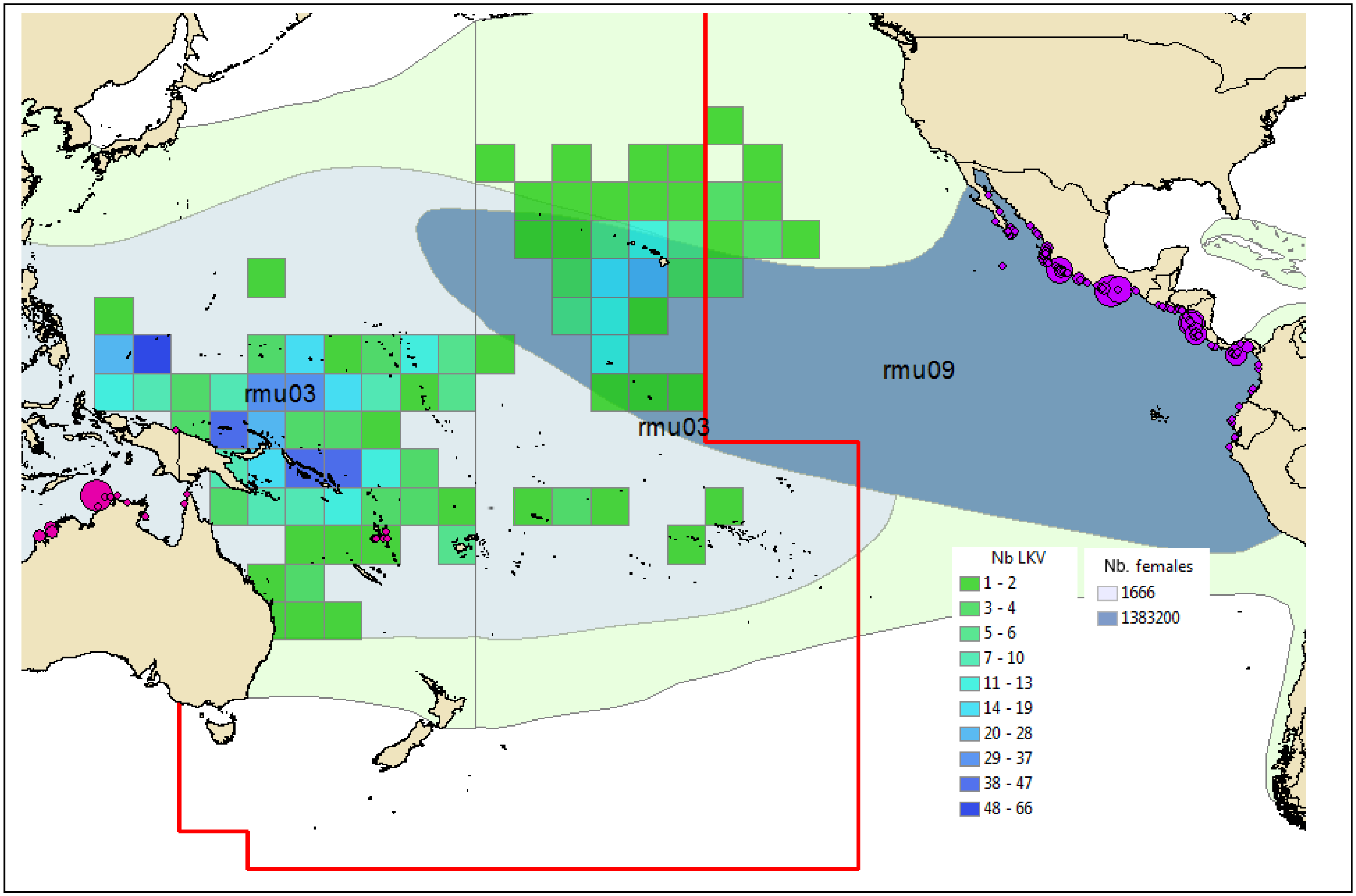


Figure 20. Input information for the relative abundance surface for olive ridley sea turtle (*Lepidochelys olivacea*, LKV) from the first workshop. The shaded areas are taken from the SWOT and represent RMU boundaries for the Pacific Ocean. Blue shading indicates relative abundance of nesting females (the number of females is estimated). Circles ranging in color from pink to blue indicate nesting sites. The total number of turtle interactions recorded by observers on purse seine and longline vessels is shown in 5x5 grids. Red lines indicate the WCPF Convention Area boundary. Note: When including this figure from the first workshop report in the final workshop report, it was noticed that no purse seine data were included (thus only longline data are shown), and only the color scheme for plotting was modified.

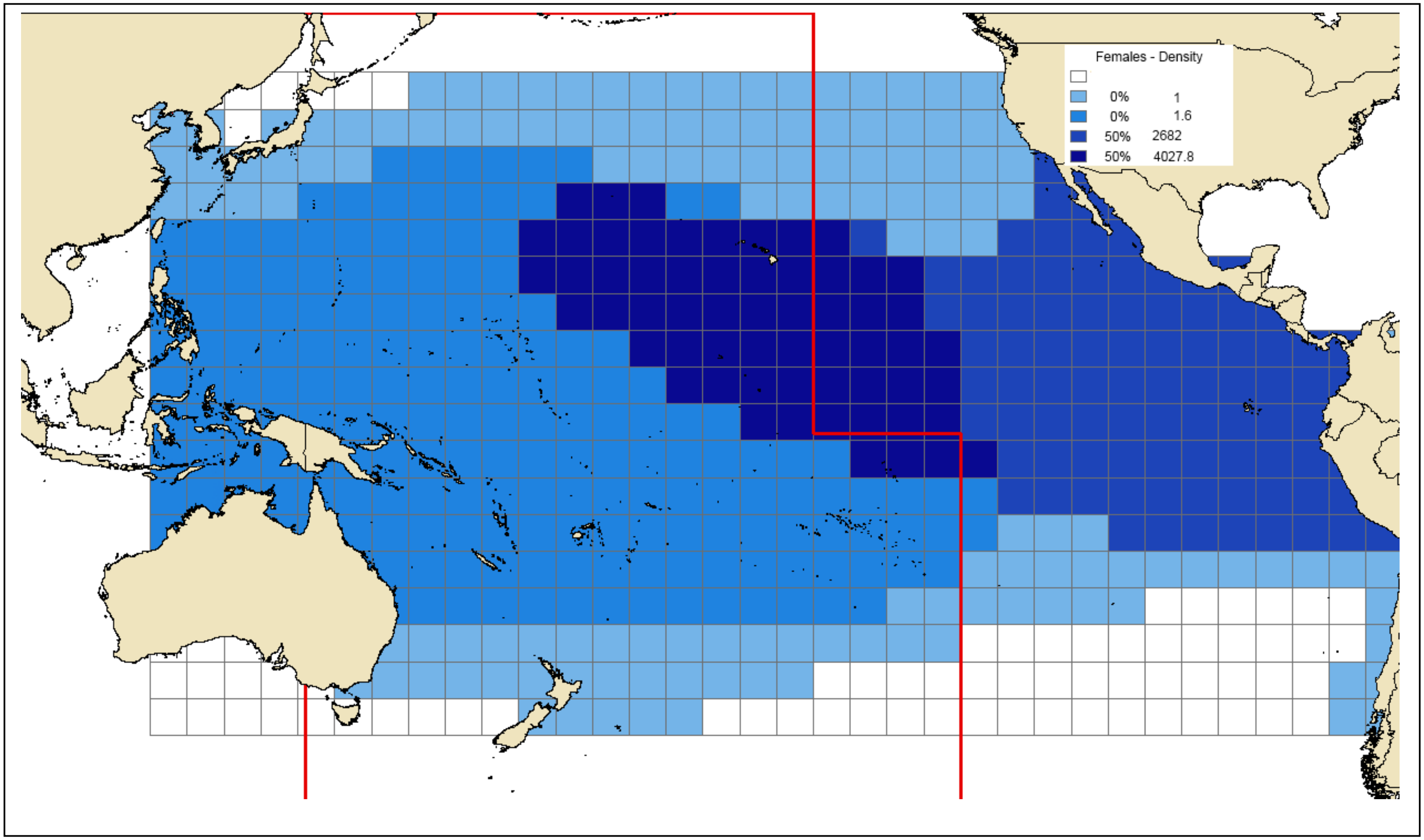


Figure 21. Relative abundance surface for olive ridley sea turtle (*Lepidochelys olivacea*) from the first workshop. The shading represents the relative abundance surface (blue areas from the preceding figure) weighted by the number of nesting females in each area (from the preceding figure) with the weighting categories listed as "density" in the legend. "Females" in the legend indicates the percentage of estimated nesting females per area. Where shown, white areas represent areas outside the global distribution of the species. Red lines indicate the WCPF Convention Area boundary.

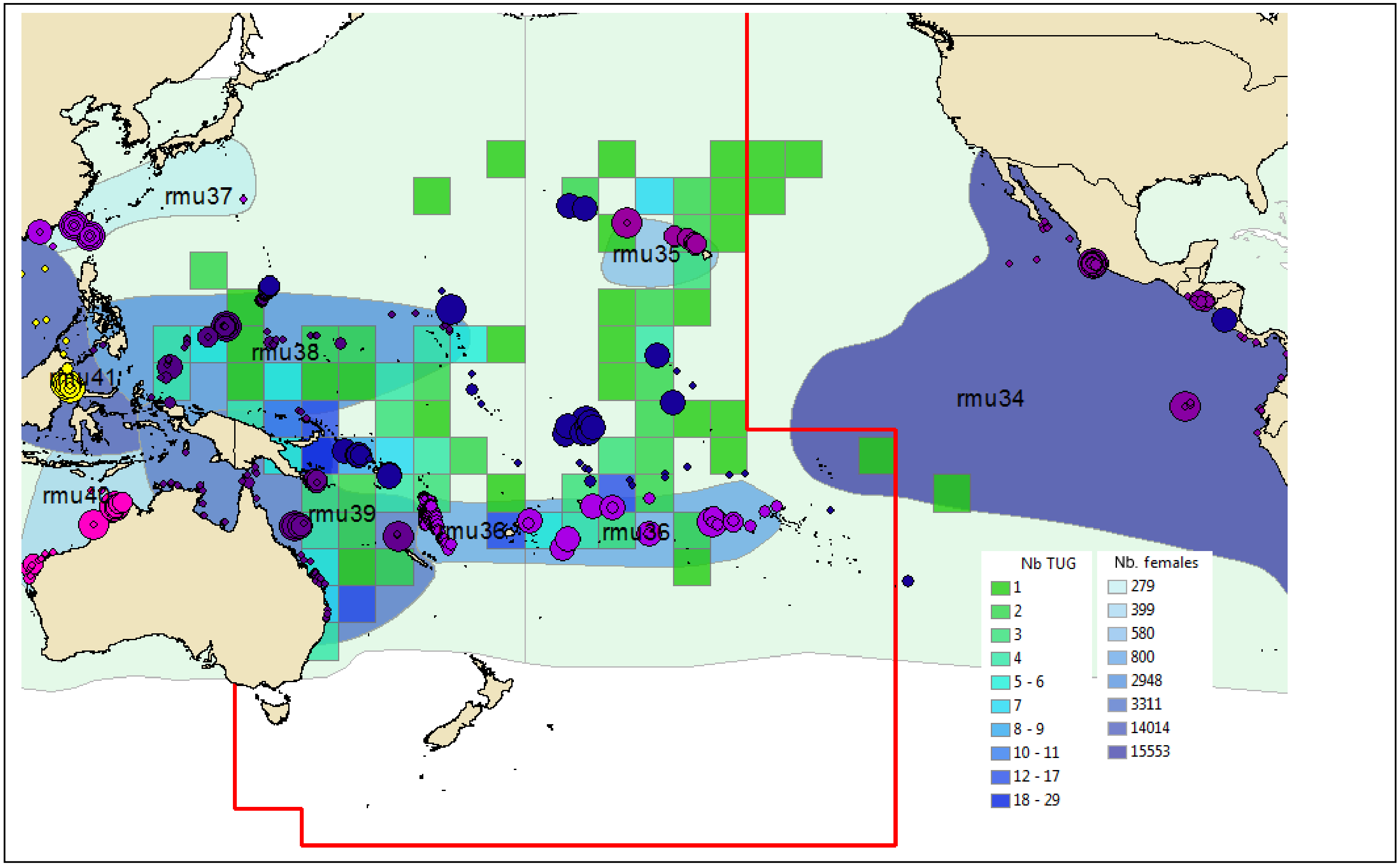


Figure 22. Input information for the relative abundance surface for green sea turtle (*Chelonia mydas*, TUG) from the first workshop. The shaded areas are taken from the SWOT and represent RMU boundaries for the Pacific Ocean. Blue shading indicates relative abundance of nesting females (the number of females is estimated). Circles ranging in color from pink to blue indicate nesting sites. The total number of turtle interactions recorded by observers on purse seine and longline vessels is shown in 5x5 grids. Red lines indicate the WCPF Convention Area boundary. Note: When including this figure from the first workshop report in the final workshop report, it was noticed that no purse seine data were included (thus only longline data are shown), and only the color scheme for plotting was modified.

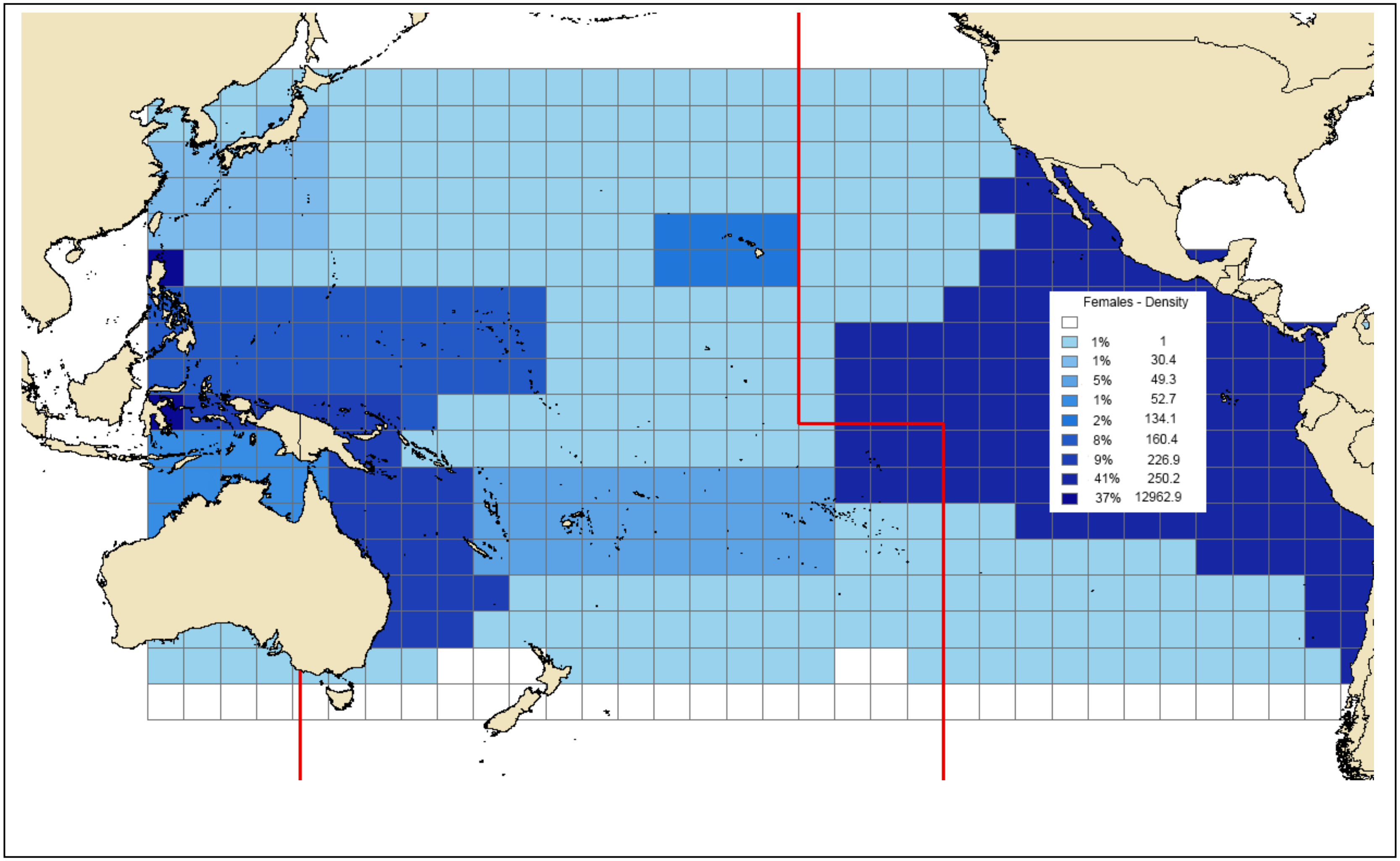


Figure 23. Relative abundance surface for green sea turtle (*Chelonia mydas*) from the first workshop. The shading represents the relative abundance surface (blue areas from the preceding figure) weighted by the number of nesting females in each area (from the preceding figure) with the weighting categories listed as "density" in the legend. "Females" in the legend indicates the percentage of estimated nesting females per area. Where shown, white areas represent areas outside the global distribution of the species. Red lines indicate the WCPF Convention Area boundary.

The system showed the previously used maps as prior information (Figures 24-27, upper panels), and asked experts to agree with the prior map, or to overwrite it with their perception of relative turtle abundance. The expert responses were then synthesised into a consensus distribution in a model-based framework. The consensus model was designed specifically for the relative abundance context to address three challenges:

1. Unevenness of the categories (the extreme categories were small compared with the intermediate categories);
2. Incomplete answers (participants had the option to answer with “don't know” for parts of the map); and
3. The potential lack of smoothness of the consensus map.

The model used for the consensus mapping employed a latent (underlying) continuous relative abundance map, which allowed for smoothing and scaling of incomplete answers. An explicit mapping between the continuous underlying distribution and the categorical answers allowed accounting for unevenness of the categorical answers on the continuous scale.

Of approximately 25 invited participants, between nine and thirteen experts submitted responses during the first round of the Delphi survey (Table 14). While some respondents' answers reflected the prior SWOT maps, many respondents chose to alter these maps in the first round. As a result, the first-round consensus maps had both elements of the prior SWOT maps, but there were also large areas with disagreements between experts. During the second round, many respondents changed their answer to reflect all or parts of the round-one consensus distribution. As a result, agreement generally increased, suggesting that the Delphi process worked to achieve greater consensus. Although fewer experts submitted answers during the second round, new people also contributed answers for all but one species (*D. coriacea*). The results of the second round of the Delphi survey are shown in the lower panels of Figures 24-27 and the full report on the Delphi survey is attached as *Annex M*.

Table 14. Number of respondents in each of the two rounds of the Delphi survey of the relative abundance of sea turtles in the Pacific Ocean.

Round	*Dermochelys coriacea (DKK)*	*Caretta caretta (TTL)*	*Lepidochelys olivacea (LKV)*	*Chelonia mydas (TUG)*
1	12	11	9	13
2	7	7	7	8
Total	12	12	11	14

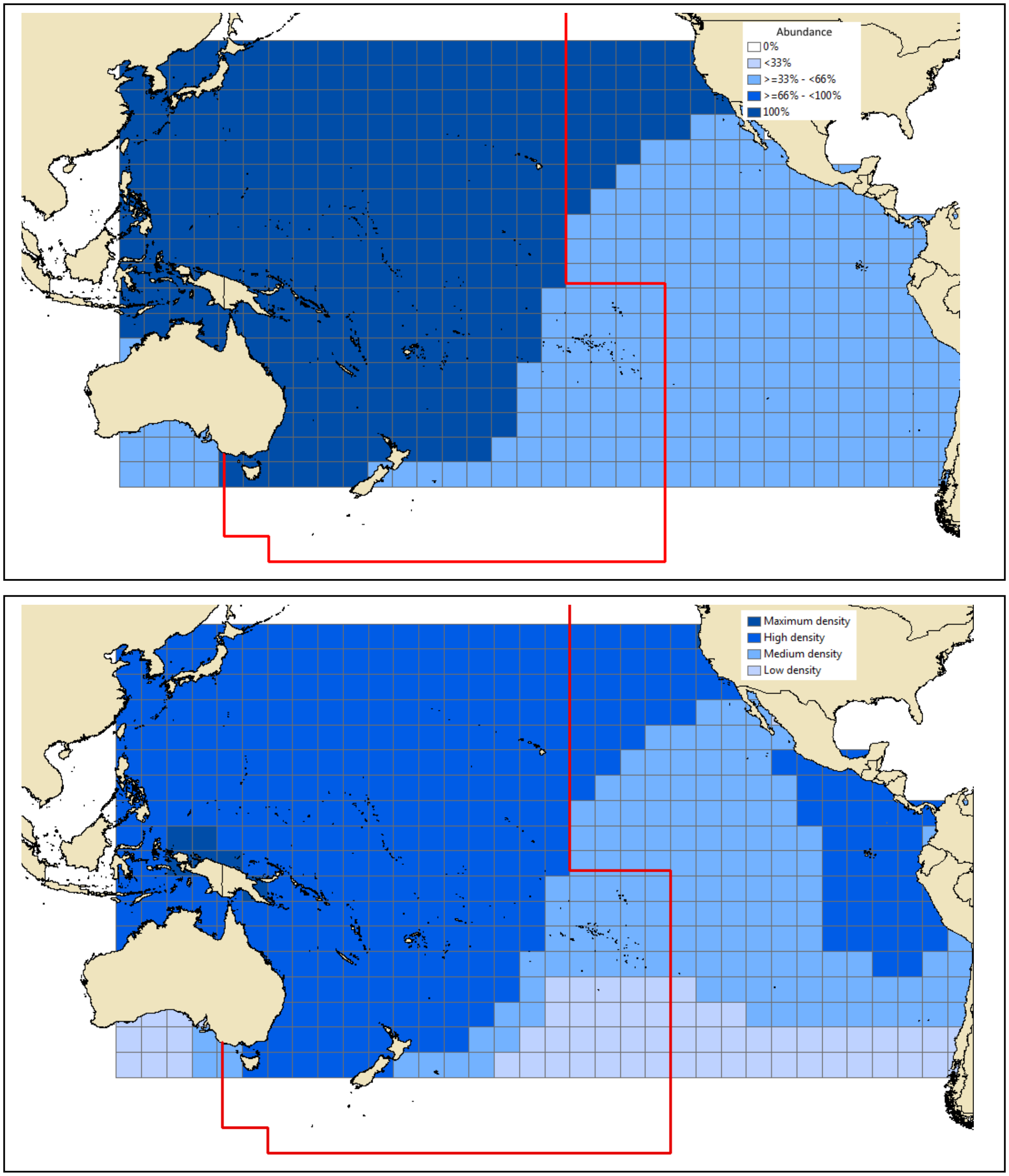


Figure 24. Initial map offered to Delphi survey participants (upper panel) and resulting map after two rounds of surveys (lower panel) for leatherback sea turtle (*Dermochelys coriacea*). Red lines indicate the WCPF Convention Area boundary.

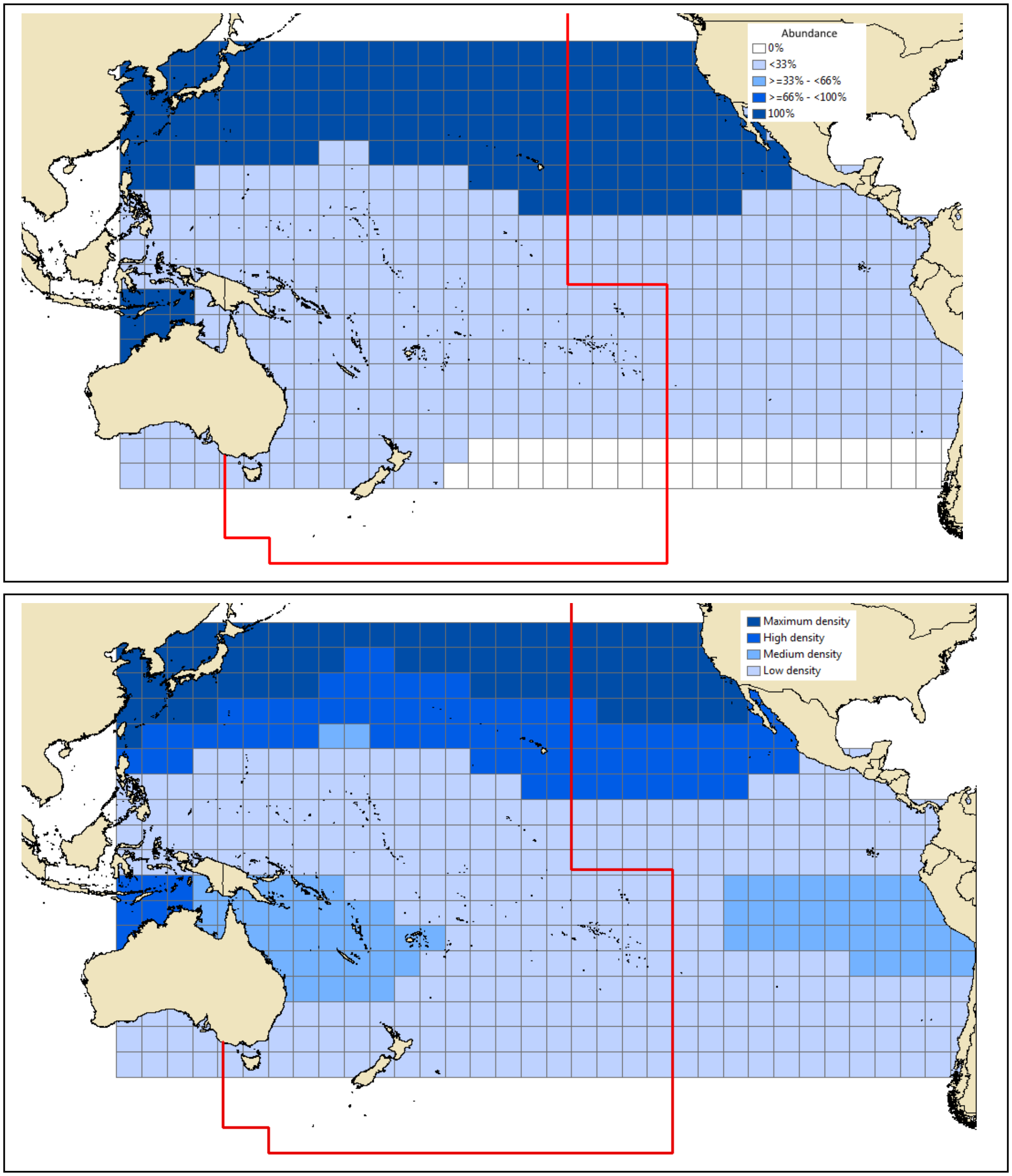


Figure 25. Initial map offered to Delphi survey participants (upper panel) and resulting map after two rounds of surveys (lower panel) for loggerhead sea turtle (*Caretta caretta*). Red lines indicate the WCPF Convention Area boundary.

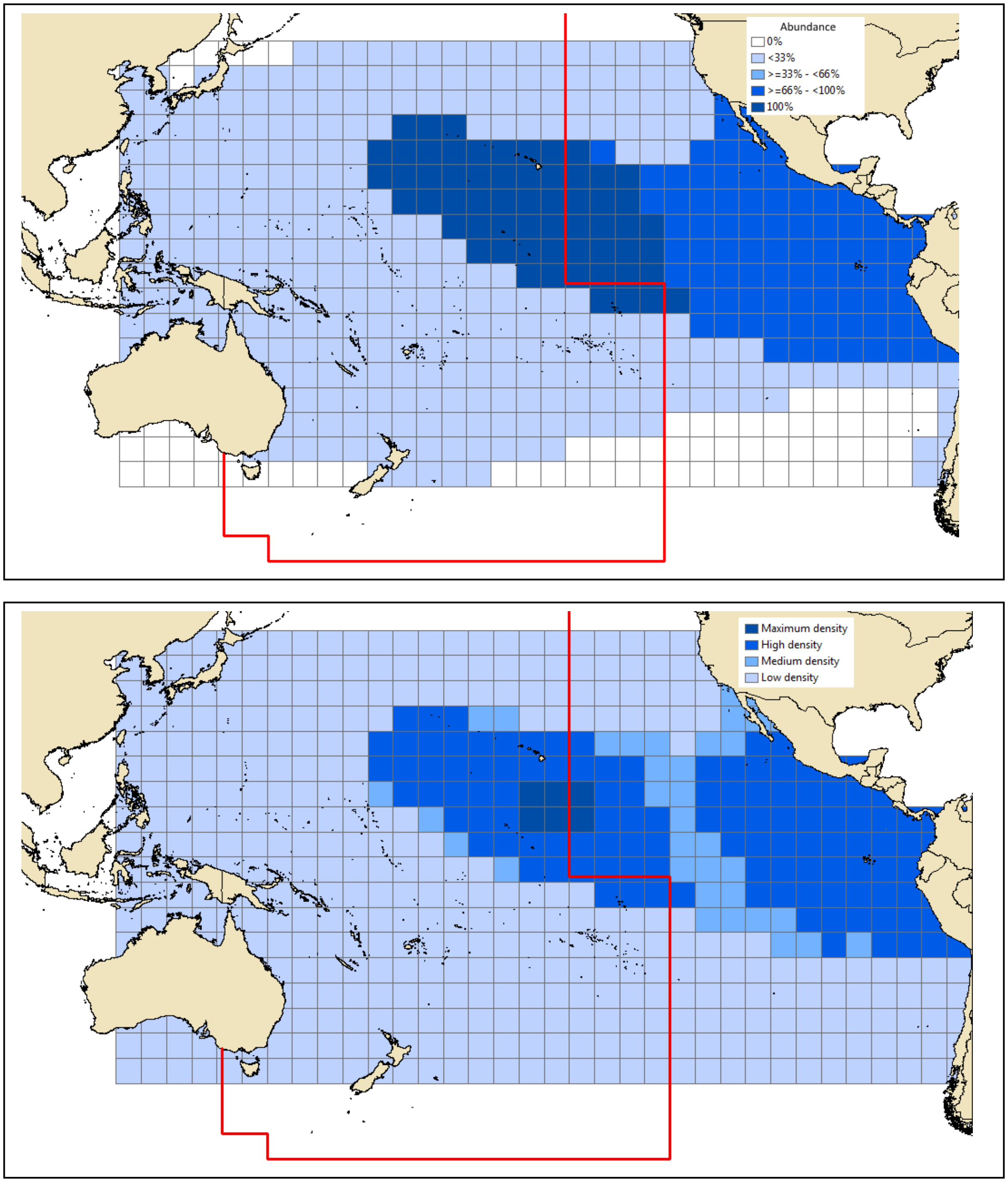
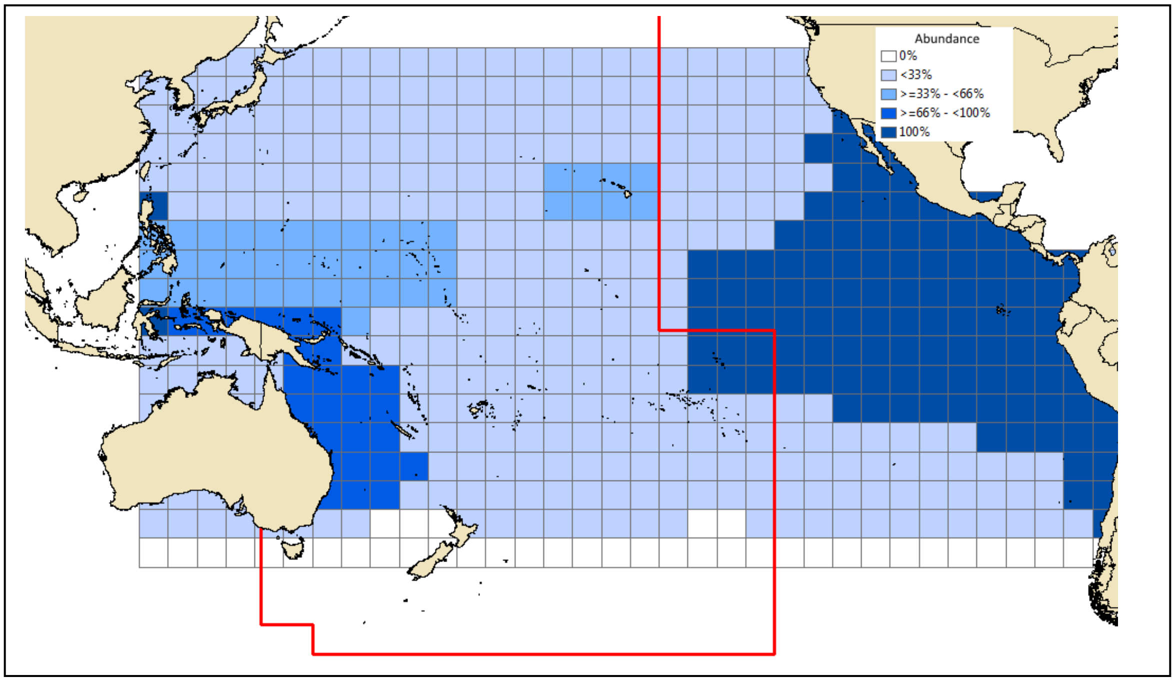


Figure 26. Initial map offered to Delphi survey participants (upper panel) and resulting map after two rounds of surveys (lower panel) for olive ridley sea turtle (*Lepidochelys olivacea*). Red lines indicate the WCPF Convention Area boundary.



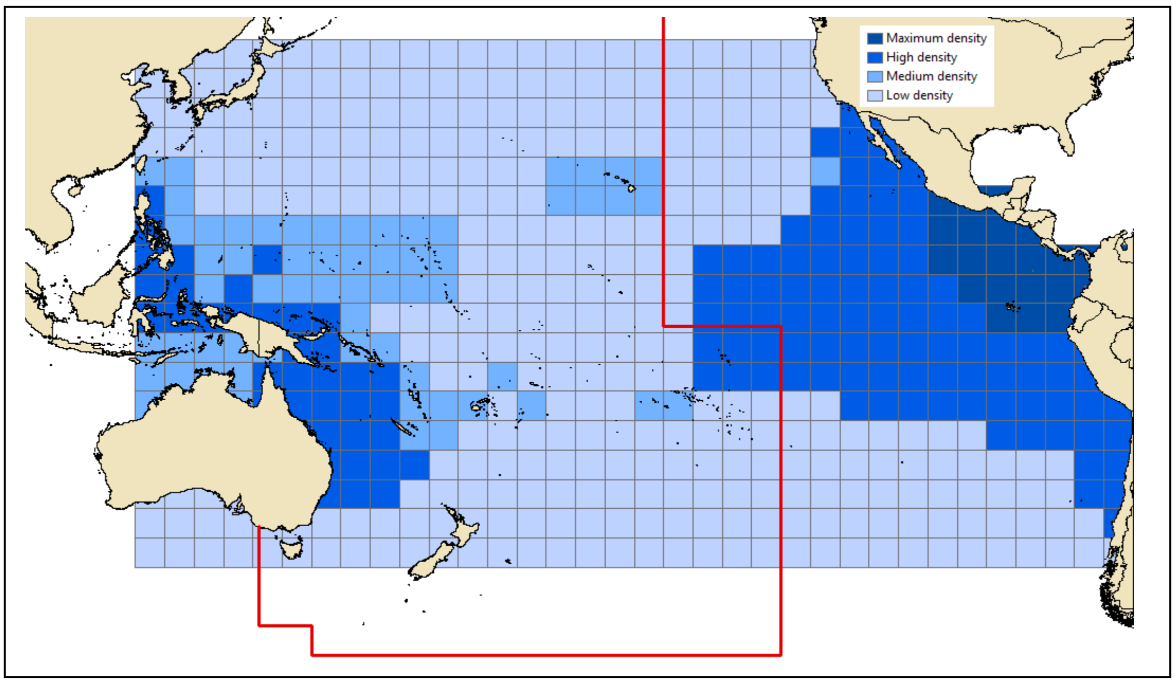


Figure 27. Initial map offered to Delphi survey participants (upper panel) and resulting map after two rounds of surveys (lower panel) for green sea turtle (*Chelonia mydas*). Red lines indicate the WCPF Convention Area boundary.

4.4.2 *Second Workshop Outcomes*

Some workshop participants who had also participated in the Delphi survey complimented the work noting that the objective of providing a peer review of the maps from the first workshop had been achieved. They further noted that the level of response from experts reflected a positive attitude toward collaboration with the workshop's analysis. Nevertheless, there are limits to existing knowledge regarding the at-sea distribution of sea turtles and thus even with excellent cooperation the relative abundance maps are bound to be incomplete and uncertain. Some workshop participants remarked that their knowledge of sea turtle distribution at sea was limited to reports of interactions with fisheries, but that such interactions did not necessarily reflect abundance.

Participants discussed the advantages and disadvantages of providing survey respondents with an initial map in the first round of the Delphi survey. Participants noted that in general the first round maps were strongly influenced by the initial maps (which reflected the SWOT maps known to many of the respondents), whereas in the second round survey respondents appeared more willing to alter the map having seen the range of opinions from respondents in the first round. Participants considered that maps for some species (e.g. leatherback) may be more reliable than for other species (e.g. green) simply because of a general lack of knowledge about these species or a lack of knowledge by the experts participating in the Delphi survey about these species. Dragonfly and SPC noted that the survey's agreement score could potentially be used to weight the survey outputs to reflect uncertainty.

J. Bourjea gave a presentation on simulations of the active dispersal of hatchlings and juveniles of leatherback and loggerhead turtles in various ocean basins, with a special focus on the critically endangered western Pacific leatherback turtle population nesting in Jamursba-Medi (Indonesia). An Individual Based Model (STAMM) is used to simulate the active dispersal of hatchlings and juveniles under the influence of ocean currents and active habitat-driven swimming movements. . Movements are assumed to be motivated by the search for food and constrained by the need to stay in suitable water temperatures. A key element of this model is the definition of an age-dependent thermal habitat suitability index as well as a feeding habitat which takes into account the evolution of food requirements with age. The simulation presented during the workshop concerns the active dispersal of 5000 particles (hatchlings and then juveniles) over a period of 18 years from Jamursba-Medi (Bird's Head Peninsula, New Guinea), a main nesting beach of the Western Pacific leatherback population. Even if the results only provide insights on the dispersal of juvenile leatherbacks from a single nesting site, they clearly show how oceanic variability, i.e. variability of ocean currents, sea surface temperature and primary production, likely drive the spatio-temporal distribution of juveniles leatherback in the open ocean. These juveniles are critically subject to interactions with longline fisheries. Simulation of the active dispersal of loggerheads in the Indian Ocean and leatherbacks in the Atlantic Ocean were also presented. In the future, such a modeling approach might be of great use to estimate the open ocean distribution of sea turtles of different species and different classes of age. This will be very useful in improving the current Regional Management Units boundaries. Output from the leatherback model for the Pacific was input to the Delphi survey. A similar model for loggerhead turtles is being tested in the Indian Ocean and will be adapted for the Pacific. Noting that even very small turtles can swim and that their ability to determine their position depends on current strength relative to their swimming ability and individual needs (i.e. food and temperature), the presenter highlighted the need for more tagging studies targeting juveniles to inform the active swimming component of the model.

The workshop then discussed whether and how the Delphi survey results should be incorporated into the overall modelling framework. SPC initially proposed three options:

- Do not use the Delphi results (instead rely on the set-level model to predict turtle relative abundance based on oceanographic variables (e.g. SST, net primary productivity, distance to shore, etc.);
- Use the Delphi results in, and drop the habitat predictors from, the set-level model;
- Use a hybrid approach in which the set-level model contains appropriate oceanographic variables and is used to predict the maximum interaction rate for each species in optimum habitat (assumed to be high abundance areas in the Delphi results) and then that maximum interaction rate is scaled geographically to the areas with lower abundance.

In discussing these options the workshop noted that only the Delphi maps would account for the presence of sea turtle nesting sites in some areas that therefore have higher abundances but are otherwise similar in an oceanographic sense. Furthermore, the Delphi maps allow for application of the model into areas that are unobserved in the dataset thereby helping to inform the set-level model (e.g. the model is likely to predict high loggerhead abundances at the 18°C isotherm because that association is well-documented in the well-observed US (Hawaii) longline fishery; however, it is not known whether that relationship holds in other areas of the Pacific).

Upon further consideration, SPC and Dragonfly advised that incorporating the agreement scores as a measure of uncertainty might introduce additional, unnecessary error into the model since the final Delphi map outputs already incorporated this uncertainty to some extent. The workshop agreed to adopt the hybrid approach above for initial testing.

4.5 Combining Model Outputs in Monte Carlo Simulations for the Entire Fishery

4.5.1 *First Workshop Outcomes*

SPC presented an overview of the simulation model and suggested that the key variables to focus on in the scenario testing are hook category and bait type. It was thus suggested that scenarios be formulated based on combinations of fleet, fishing strategy, hook category and bait type, with each scenario run for each of the four turtle species.

While these variables would be the focus of the testing, the full suite of variables used in the set-level and condition models need to be specified for the simulation model. This can be accomplished by using the average values of the required variables for the specific fleet and fishing strategy being tested.

SPC clarified that fleets had been divided into shallow and deep fishing strategies based on species composition and time of day of setting, and then selecting the hbf range that best characterized shallow and deep strategies for that fleet. Using this method a break was established at 10 hbf for all fisheries except for the United States for which shallow sets are regulated as those <15 hbf (but in practice United States shallow set fisheries usually fish with considerably fewer than 15 hbf). Participants were reminded that the fleet-fishing strategy combinations are shown as rows in Table 1[6].

[6] Please see Section 3.2.2 for the updated methodology and splits used in the second workshop

One participant asked SPC to look into whether catch and effort data submitted to the WCPFC in aggregated form contains the number of sets by hbf or only the number of hooks.

SPC highlighted a number of issues related to scenario definition for the consideration of the workshop:

- The possibility of predicting interaction rates for each 5x5 grid individually to take account of species-specific habitat preferences (as indicated by SST) as an alternative to using a relative abundance surface.
- The possibility of re-classifying the parameter estimate for "small J-hooks" for the simulation given that there is a relatively lower level of credibility associated with that estimate (due to it being data-poor).
- The possibility of using the small circle hook estimate for the small Japanese tuna and Teracima (T hook) category.

The workshop agreed that for the second issue it would be appropriate to conduct sensitivity runs with the existing estimate of small J hook parameters, then again with resetting this parameter equal to that for the small T hook and if there is a difference, running the model a third time with a parameter intermediate to that of the first two runs.

It was discussed that in general scenarios involving simulating combinations of variables that are not informed by the data should be avoided. An exception to this might be encountered when trying to represent fleets for which there are no observer data and thus little information on gear characteristics. In such cases, consultation with national authorities will be used to supplement the information available.

Participants suggested that defining a baseline will require careful interpretation since it will represent shifts of gear characteristics of differing magnitudes over different periods of time for different fleets. SPC clarified that the baseline (current) scenario would be defined as starting in 2010 and running through 2014 or 2015, depending on the data source.

Two ideas for priority scenarios were identified:

- Full implementation of alternate hooks and/or fish bait for all shallow set longline fisheries with all deep set fisheries operating under the status quo; full implementation of use of alternate hooks and/or fish bait for all deep set longline fisheries with all shallow set fisheries operating under the status quo; and full implementation in both fleets.
- Testing for the deep set fishery of the effects on interaction and at-vessel mortality in the WCPO as a whole of removing one or more of the shallowest hooks closest to the floats.

4.5.2 *Activities between the First and Second Workshops*

SPC investigated several of the issues raised by the first workshop.

First, SPC confirmed that hbf disaggregated catch and effort data has been submitted to the WCPFC. These data were used to allocate effort between shallow and deep sets (Section 3.2.2). However, it is important to note that hbf disaggregated data were limited to the WCPO, with no coverage for the EPO.

Second, with regard to low standardised interaction rates for small J hooks, revision of the set interaction rate model with the revised Chinese Taipei dataset showed the sensitivity of the small J-hook effect to the data set being modelled (Section 4.1.2). As such, SPC considered that the small J hook effect might change following the finalisation of the set interaction rate models at the second workshop, and that this issue could be dealt with following finalisation of the set-level interaction rate model, if required.

On 27 April 2016, WCPFC Circular 2016-15 was issued containing a list of 51 proposed mitigation scenarios for the simulation modelling. As recommended in the first workshop, the mitigation scenarios were designed to focus on hook type, bait type and removal of the first hooks adjacent to each float (Option A) or the first two hooks adjacent to each float (Option B). It was originally intended to proceed with some initial runs of these scenarios to serve as a starting point for the second workshop. However, due to the need to revise the set-level, hook position and condition models both structurally (see Sections 4.1.2, 4.2.2 and 4.3.2) and in terms of the additional observer data received from Japan, and the constraints of the data confidentiality conditions which prevent analysis outside of the workshop sessions, this could not be undertaken for the full data set.

The circular noted that the original list of 51 scenarios might be expanded if initial runs showed that applying both large circle hook and finfish bait mitigation to shallow set longliners fishing for swordfish (such as in Scenarios #49-51) resulted in substantial reduction in interaction and mortality rates. In particular, some of the mitigation scenarios involving mitigation of only those fleets that are not currently subject to CMM 2008-03 (i.e. deep set and shallow-set not fishing for swordfish; Scenarios #1-#15, #17-#31 and #33-#48) might be supplemented by including both hook type and bait type mitigation for shallow set longliners fishing for swordfish (i.e. which are only subject to one of these mitigation requirements at present). In preparing the code for the models to be run in the second workshop, and running this code for the available, SPC in-house data only, it was proposed to expand the number of mitigation scenarios modelled from 51 to 60. The expanded list of scenarios is shown in Table 15.

Table 15. Specification of scenarios for sea turtle mitigation. SQ = status quo. Scenarios #1-#51 were specified in WCPFC Circular 2016-15 of 27 April 2016. Scenarios #52-60 were developed by SPC intersessionally. Scenarios #61-72 were suggested in the second workshop.

	Swordfish-targeting shallow set	Other shallow set	Deep set
1	SQ	SQ	SQ
2	SQ	SQ with finfish bait	SQ
3	SQ	SQ with large circle hooks	SQ
4	SQ	SQ with finfish bait and large circle hooks	SQ
5	SQ	SQ	SQ with finfish bait
6	SQ	SQ with finfish bait	SQ with finfish bait
7	SQ	SQ with large circle hooks	SQ with finfish bait
8	SQ	SQ with finfish bait and large circle hooks	SQ with finfish bait
9	SQ	SQ	SQ with large circle hooks
10	SQ	SQ with finfish bait	SQ with large circle hooks
11	SQ	SQ with large circle hooks	SQ with large circle hooks
12	SQ	SQ with finfish bait and large circle hooks	SQ with large circle hooks
13	SQ	SQ	SQ with finfish bait and large circle hooks
14	SQ	SQ with finfish bait	SQ with finfish bait and large circle hooks
15	SQ	SQ with large circle hooks	SQ with finfish bait and large circle hooks
16	SQ	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks
17	SQ	SQ	SQ and ***hook removal option A***
18	SQ	SQ with finfish bait	SQ and ***hook removal option A***
19	SQ	SQ with large circle hooks	SQ and ***hook removal option A***
20	SQ	SQ with finfish bait and large circle hooks	SQ and ***hook removal option A***
21	SQ	SQ	SQ with finfish bait and ***hook removal option A***
22	SQ	SQ with finfish bait	SQ with finfish bait and ***hook removal option A***
23	SQ	SQ with large circle hooks	SQ with finfish bait and ***hook removal option A***
24	SQ	SQ with finfish bait and large circle hooks	SQ with finfish bait and ***hook removal option A***
25	SQ	SQ	SQ with large circle hooks and ***hook removal option A***
26	SQ	SQ with finfish bait	SQ with large circle hooks and ***hook removal option A***
27	SQ	SQ with large circle hooks	SQ with large circle hooks and ***hook removal option A***
28	SQ	SQ with finfish bait and large circle hooks	SQ with large circle hooks and ***hook removal option A***
29	SQ	SQ	SQ with finfish bait and large circle hooks and ***hook removal option A***
30	SQ	SQ with finfish bait	SQ with finfish bait and large circle hooks and ***hook removal option A***
31	SQ	SQ with large circle hooks	SQ with finfish bait and large circle hooks and ***hook removal option A***
32	SQ	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks and ***hook removal option A***
33	SQ	SQ	SQ and ***hook removal option B***
34	SQ	SQ with finfish bait	SQ and ***hook removal option B***
35	SQ	SQ with large circle hooks	SQ and ***hook removal option B***

	Swordfish-targeting shallow set	Other shallow set	Deep set
36	SQ	SQ with finfish bait and large circle hooks	SQ and ***hook removal option B***
37	SQ	SQ	SQ with finfish bait and ***hook removal option B***
38	SQ	SQ with finfish bait	SQ with finfish bait and ***hook removal option B***
39	SQ	SQ with large circle hooks	SQ with finfish bait and ***hook removal option B***
40	SQ	SQ with finfish bait and large circle hooks	SQ with finfish bait and ***hook removal option B***
41	SQ	SQ	SQ with large circle hooks and ***hook removal option B***
42	SQ	SQ with finfish bait	SQ with large circle hooks and ***hook removal option B***
43	SQ	SQ with large circle hooks	SQ with large circle hooks and ***hook removal option B***
44	SQ	SQ with finfish bait and large circle hooks	SQ with large circle hooks and ***hook removal option B***
45	SQ	SQ	SQ with finfish bait and large circle hooks and ***hook removal option B***
46	SQ	SQ with finfish bait	SQ with finfish bait and large circle hooks and ***hook removal option B***
47	SQ	SQ with large circle hooks	SQ with finfish bait and large circle hooks and ***hook removal option B***
48	SQ	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks and ***hook removal option B***
49	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks
50	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks and ***hook removal option A***
51	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks and ***hook removal option B***
52	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks	SQ
53	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks	SQ with finfish bait
54	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks	SQ and ***hook removal option A***
55	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks	SQ with finfish bait and ***hook removal option A***
56	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks	SQ and ***hook removal option B***
57	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks	SQ with finfish bait and ***hook removal option B***
58	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks	SQ with large circle hooks
59	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks	SQ with large circle hooks and ***hook removal option A***
60	SQ with finfish bait and large circle hooks	SQ with finfish bait and large circle hooks	SQ with large circle hooks and ***hook removal option B***
61	SQ with finfish bait and large circle hooks	SQ	SQ with finfish bait and large circle hooks
62	SQ with finfish bait and large circle hooks	SQ	SQ with finfish bait and large circle hooks and ***hook removal option A***
63	SQ with finfish bait and large circle hooks	SQ	SQ with finfish bait and large circle hooks and ***hook removal option B***
64	SQ with finfish bait and large circle hooks	SQ	SQ
65	SQ with finfish bait and large circle hooks	SQ	SQ with finfish bait
66	SQ with finfish bait and large circle hooks	SQ	SQ and ***hook removal option A***
67	SQ with finfish bait and large circle hooks	SQ	SQ with finfish bait and ***hook removal option A***
68	SQ with finfish bait and large circle hooks	SQ	SQ and ***hook removal option B***
69	SQ with finfish bait and large circle hooks	SQ	SQ with finfish bait and ***hook removal option B***
70	SQ with finfish bait and large circle hooks	SQ	SQ with large circle hooks
71	SQ with finfish bait and large circle hooks	SQ	SQ with large circle hooks and ***hook removal option A***
72	SQ with finfish bait and large circle hooks	SQ	SQ with large circle hooks and ***hook removal option B***

4.5.3 *Second Workshop Outcomes*

SPC explained that, as described in Section 4.1.1, the response variable of the set level interaction rate model is the probability of at least one turtle interaction with the set. The first workshop agreed that the predicted probability of at least one turtle interaction would be scaled by the average (non-zero) number of turtle interactions per set, to account for the rare occurrence of multiple sea turtle interactions within the same set. The model was thus coded to perform this scaling with the following average (non-zero) interactions per set by species calculated in the first workshop and updated in the second workshop as follows: leatherback – 1.01 individuals; loggerhead – 1.17 individuals; olive ridley – 1.18 individuals; and, green turtles – 1.08 individuals. This low average number of interactions per set highlights the rarity of multiple interactions on a single set despite the tendency for sea turtles to display a clumped distribution.

SPC also noted the need to convert from model output in hooks to units of sets. This was done using flag, target strategy, and gear-specific average numbers of hooks per set.

Participants asked for clarification on how the removal of the first (Option A) or first and second (Option B) closest hook positions to the float is implemented in the mitigation scenario simulations, SPC explained that the reduction in catch is estimated by the proportion of interactions assumed to have occurred on the first and second closest hook positions to the float, however, effort in total sets and total hooks remains the same.

It was also noted that the American Samoa deep-set longline fishery has already implemented similar mitigation measures in 2011 (*Annex E*). SPC confirmed that the simulation model did not take account of this pre-existing mitigation measure, but that the effort in this fishery is relatively low and thus impacts on the simulation model would be minimal.

The workshop discussed a potential issue arising from the fact that CMM 2008-03 does not specify a definition of large circle hooks, yet this analysis has applied such a definition (see Table 5). It was noted that all scenarios involving a change to large circle hooks assume those large circle hooks conform to the workshop definition and this ensures that all scenarios are comparable. In reality, however, under the existing CMM some CCMs may be implementing circle hooks which they have defined as large, but which do not conform to this workshop's definition.

Participants considered that adding the additional scenarios (#52-#60) proposed by SPC intersessionally would be useful. Participants also discussed adding additional scenarios to consider requiring deep sets to use "large" hooks of any kind, but it was noted that the set-level interaction model does not predict for "large" hooks of any kind, only large circle hooks. Participants agreed that another set of 12 scenarios examining the full range of deep set mitigation measures in combination with shallow swordfish targeting fisheries having to implement both large circle hooks and finfish bait, and shallow other fisheries not having to implement any mitigation, should be undertaken (Scenarios #61-#72). Some participants noted that previous research suggests that applying both hook type and bait type mitigation is largely redundant, but this could not be addressed in the construction of the set-level interaction rate model. Participants suggested that presenting results as relative to the status quo for all fleets (Scenario #1) was preferable to presenting absolute turtle numbers.

As a test of the sensitivity of modelled simulations to the Delphi survey results, SPC compared simulation outputs with (i.e. the hybrid approach, see Section 4.4.3) and without scaling of interaction rates using the agreed Delphi survey maps. The results showed that the model output is largely insensitive to scaling with the Delphi maps. This is not surprising as the model output is in relative space, and thus proportional reductions resulting from mitigation applied to a given flag-strategy-gear configuration will be the same, regardless of the relative abundance map. Marked differences would only be expected with substantial gear configuration-specific differences in overlap between relative abundance and effort, which is not the case for the majority of the simulated effort.

Participants noted that mitigation through finfish bait resulted in reductions in interactions in the shallow-other group, and sought clarification on the extent of mixed finfish-squid or squid baiting regimes in the simulation model for this effort category. SPC responded that five flags had simulated effort with finfish-squid baiting regimes, with comparatively limited usage of pure squid, and these fleets' effort accounts for a notable proportion of the shallow-other effort.

SPC provided figures for the percentage of the total turtles produced from the simulation model for each species for WCPO and Pacific-wide in order to help interpret the matrices for all turtles combined. For the WCPO the percentages were 14% leatherback, 36% loggerhead, 35% olive ridley and 14% green sea turtles, and for the Pacific as a whole the percentages were 14% leatherback, 33% loggerhead, 38% olive ridley and 15% green sea turtles.

SPC undertook simulation model runs for the WCPO (Figures 28-32) and for the Pacific as a whole (*Annex L*). The format of the results can be linked to the scenarios in Table 15 using the following key (scenario numbers shown in cells):

deep/shlw	SWO=SQ OTH=SQ	SWO=SQ, OTH=fsh	SWO=SQ OTH=CL	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1	2	3	4	64	52
fsh	5	6	7	8	65	53
CL	9	10	11	12	70	58
A	17	18	19	20	66	54
B	33	34	35	36	68	56
fsh A	21	22	23	24	67	55
fsh B	37	38	39	40	69	57
CL A	25	26	27	28	71	59
CL B	41	42	43	44	72	60
CL fsh	13	14	15	16	61	49
CL fsh A	29	30	31	32	62	50
CL fsh B	45	46	47	48	63	51

Rows and columns represent mitigation options for deep and shallow set longlines respectively, with shallow set mitigation further split between swordfish fisheries regulated through CMM 2008-03 (SWO =) and other fisheries (OTH =). Other acronyms used are "SQ" for status quo, "CL" for large circle hooks, "fsh" for whole finfish bait, "A" for hook removal option A (removal of the hook position closest to floats), and "B" for hook removal option B (removal of the two hook positions closest to floats).

From these results the following observations were made:

1. For all four species there were limited reductions in interactions, and even more limited reductions in at-vessel mortalities, resulting from strengthening mitigation for the fisheries already regulated by CMM 2008-03 (i.e. self-identified shallow-set effort targeting swordfish).

2. For all four species, shallow-set mitigation measures deliver substantially weaker reductions in at-vessel mortalities compared to deep-set mitigation measures, due to lower at-vessel mortalities in shallow set fisheries, and because some CCMs have already implemented mitigation based on CMM 2008-03 for their shallow swordfish fisheries.

3. For all four species, deep-set mitigation measures deliver stronger reductions in at-vessel mortalities compared to interactions. This is a result of the fact that sea turtles caught in deep sets have a higher probability of at-vessel mortality due to asphyxiation as documented in previous studies.

4. For all four sea turtle species combined, deep set mitigation measures result in a greater reduction in overall interactions than shallow set mitigation measures. Although interactions are more likely in shallow sets, the greater amount of effort in deep set fisheries (4 times greater effort in deep set than shallow set fisheries) contributes to this result. However, for one species (loggerhead), the maximum reduction obtained with deep set mitigation is less than the maximum reduction obtained with shallow set mitigation.

5. For all four species the effect of large (size 16/0 or larger, as assumed in the simulations) circle hooks in reducing interactions is greater than the effect of fish bait, but the degree of difference varies across species and across sectors (i.e. shallow versus deep).

6. In reducing both interactions and at-vessel mortalities in deep set fisheries, Option A (removal of the hook position closest to the float) is similar in effectiveness to changing to finfish bait. Option B (removal of the two hook positions closest to the float) is similar in effectiveness to changing to large circle hooks.

7. The effect of removing the two hook positions closest to the float (Option B) is greater than removing only the first hook positions closest to the float (Option A). However, the difference varies by species with the weakest mitigation effect for leatherback turtles that tend to interact with longline gear at greater depth (see above discussion on interpretation of Options A & B).

Some participants were concerned that the modelling approach was too complex given the small number of sea turtles in the database. They suggested that a smaller number of scenarios would be more appropriate. Other participants noted that the number of scenarios does not alter the power of the analysis and that the current analytical approach, though heavily caveated could still lead to important new insights.

The workshop acknowledged that it did not investigate the effects of the simulated mitigation strategies on non-turtle species including other bycatch and target species. As a result, it recognized that there will be varying implications of these sea turtle mitigation strategies both across and within fleets. The workshop also noted that improvements in the data available to address these topics (see Section 5) will assist in clarifying such effects. For example, fleets catching relatively smaller target species may have greater difficulties in adopting mitigation involving large circle hooks. Also, changes in hook or bait types may impact catch or mortality rates for other taxa.

Interactions

Total WCPO	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.811	0.942	0.772	0.983	0.755
fsh	0.924	0.735	0.866	0.696	0.907	0.678
CL	0.819	0.630	0.761	0.592	0.802	0.574
A	0.913	0.724	0.855	0.685	0.895	0.667
B	0.844	0.655	0.786	0.616	0.827	0.599
fsh A	0.853	0.664	0.795	0.625	0.836	0.608
fsh B	0.797	0.608	0.739	0.569	0.780	0.552
CL A	0.767	0.578	0.709	0.540	0.750	0.522
CL B	0.726	0.537	0.668	0.498	0.708	0.480
CL fsh	0.774	0.585	0.716	0.547	0.757	0.529
CL fsh A	0.732	0.542	0.673	0.504	0.714	0.486
CL fsh B	0.698	0.509	0.640	0.470	0.681	0.453

At-vessel mortalities

Total WCPO	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.970	0.982	0.958	0.999	0.957
fsh	0.866	0.836	0.849	0.825	0.865	0.824
CL	0.640	0.609	0.622	0.598	0.638	0.597
A	0.824	0.794	0.806	0.782	0.823	0.781
B	0.684	0.654	0.666	0.642	0.683	0.641
fsh A	0.717	0.687	0.700	0.676	0.716	0.675
fsh B	0.599	0.569	0.582	0.558	0.598	0.557
CL A	0.533	0.502	0.515	0.491	0.531	0.490
CL B	0.447	0.417	0.429	0.405	0.446	0.404
CL fsh	0.557	0.527	0.539	0.515	0.556	0.514
CL fsh A	0.466	0.436	0.449	0.425	0.465	0.424
CL fsh B	0.394	0.364	0.376	0.353	0.393	0.351

Figure 28. Simulation testing results for all sea turtle species for the Western and Central Pacific Ocean. Interactions are shown in the upper panel; at-vessel mortalities are shown in the lower panel. Cell values and colours indicates the strength of reduction relative to the status quo (SQ) shown in the upper left corner as 1.00: red = no change; green = maximum reduction. Rows and columns specify mitigation options for deep and shallow set longlines, respectively. The table of mitigation scenarios and associated text in Section 4.5.3 provides a full explanation of the formatting of these mitigation scenario outputs.

Interactions

DKK WCPO	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.799	0.932	0.757	0.980	0.737
fsh	0.922	0.721	0.854	0.679	0.902	0.659
CL	0.823	0.622	0.755	0.580	0.803	0.560
A	0.938	0.737	0.871	0.696	0.919	0.675
B	0.881	0.680	0.813	0.638	0.861	0.618
fsh A	0.873	0.672	0.805	0.630	0.853	0.610
fsh B	0.827	0.626	0.759	0.585	0.808	0.564
CL A	0.787	0.586	0.719	0.544	0.767	0.523
CL B	0.753	0.552	0.685	0.510	0.733	0.490
CL fsh	0.778	0.577	0.711	0.536	0.759	0.515
CL fsh A	0.749	0.548	0.681	0.506	0.729	0.486
CL fsh B	0.722	0.521	0.654	0.480	0.702	0.459

At-vessel mortalities

DKK WCPO	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.988	0.993	0.984	0.999	0.983
fsh	0.847	0.835	0.840	0.831	0.846	0.830
CL	0.615	0.603	0.608	0.599	0.614	0.598
A	0.863	0.851	0.856	0.847	0.862	0.846
B	0.738	0.727	0.731	0.722	0.738	0.722
fsh A	0.735	0.723	0.728	0.718	0.734	0.718
fsh B	0.632	0.621	0.625	0.616	0.632	0.615
CL A	0.533	0.521	0.526	0.516	0.532	0.516
CL B	0.457	0.445	0.450	0.440	0.456	0.440
CL fsh	0.523	0.512	0.516	0.507	0.523	0.506
CL fsh A	0.454	0.442	0.447	0.438	0.453	0.437
CL fsh B	0.390	0.379	0.383	0.374	0.390	0.373

Figure 29. Simulation testing results for leatherback sea turtles (*Dermochelys coriacea*) for the Western and Central Pacific Ocean. Interactions are shown in the upper panel; at-vessel mortalities are shown in the lower panel. Cell values and colours indicates the strength of reduction relative to the status quo (SQ) shown in the upper left corner as 1.00: red = no change; green = maximum reduction. Rows and columns specify mitigation options for deep and shallow set longlines, respectively. The table of mitigation scenarios and associated text in Section 4.5.3 provides a full explanation of the formatting of these mitigation scenario outputs.

Interactions

TTL WCPO	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.779	0.941	0.739	0.978	0.717
fsh	0.943	0.723	0.885	0.682	0.922	0.660
CL	0.856	0.635	0.797	0.594	0.834	0.572
A	0.913	0.693	0.855	0.652	0.892	0.630
B	0.858	0.638	0.799	0.597	0.837	0.575
fsh A	0.873	0.652	0.814	0.612	0.851	0.590
fsh B	0.828	0.607	0.769	0.566	0.806	0.544
CL A	0.804	0.584	0.745	0.543	0.783	0.521
CL B	0.771	0.551	0.713	0.510	0.750	0.488
CL fsh	0.822	0.602	0.764	0.561	0.801	0.539
CL fsh A	0.780	0.560	0.721	0.519	0.759	0.497
CL fsh B	0.753	0.533	0.695	0.492	0.732	0.470

At-vessel mortalities

TTL WCPO	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.971	0.984	0.961	0.999	0.960
fsh	0.887	0.858	0.870	0.847	0.885	0.846
CL	0.632	0.604	0.616	0.593	0.631	0.592
A	0.779	0.751	0.763	0.740	0.778	0.739
B	0.640	0.611	0.624	0.601	0.639	0.600
fsh A	0.697	0.669	0.681	0.658	0.696	0.657
fsh B	0.577	0.548	0.561	0.538	0.576	0.537
CL A	0.501	0.472	0.485	0.462	0.500	0.461
CL B	0.415	0.387	0.399	0.376	0.414	0.375
CL fsh	0.564	0.535	0.547	0.525	0.563	0.524
CL fsh A	0.448	0.420	0.432	0.409	0.447	0.408
CL fsh B	0.375	0.346	0.359	0.336	0.374	0.335

Figure 30. Simulation testing results for loggerhead sea turtles (*Caretta caretta*) for the Western and Central Pacific Ocean. Interactions are shown in the upper panel; at-vessel mortalities are shown in the lower panel. Cell values and colours indicates the strength of reduction relative to the status quo (SQ) shown in the upper left corner as 1.00: red = no change; green = maximum reduction. Rows and columns specify mitigation options for deep and shallow set longlines, respectively. The table of mitigation scenarios and associated text in Section 4.5.3 provides a full explanation of the formatting of these mitigation scenario outputs.

Interactions

LKV WCPO	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.847	0.952	0.815	0.989	0.804
fsh	0.913	0.760	0.865	0.728	0.902	0.717
CL	0.785	0.633	0.737	0.600	0.774	0.589
A	0.902	0.750	0.854	0.717	0.891	0.706
B	0.817	0.665	0.769	0.633	0.806	0.622
fsh A	0.831	0.679	0.783	0.647	0.820	0.635
fsh B	0.761	0.609	0.713	0.577	0.750	0.565
CL A	0.725	0.573	0.677	0.540	0.714	0.529
CL B	0.673	0.521	0.625	0.488	0.662	0.477
CL fsh	0.731	0.579	0.683	0.546	0.720	0.535
CL fsh A	0.682	0.529	0.634	0.497	0.670	0.486
CL fsh B	0.639	0.486	0.591	0.454	0.628	0.443

At-vessel mortalities

LKV WCPO	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.973	0.985	0.963	0.999	0.962
fsh	0.860	0.833	0.845	0.823	0.859	0.822
CL	0.640	0.613	0.625	0.603	0.639	0.602
A	0.836	0.809	0.821	0.799	0.835	0.798
B	0.693	0.667	0.678	0.656	0.693	0.656
fsh A	0.721	0.694	0.706	0.684	0.720	0.683
fsh B	0.602	0.575	0.587	0.565	0.601	0.564
CL A	0.539	0.512	0.524	0.502	0.538	0.501
CL B	0.451	0.425	0.436	0.414	0.451	0.414
CL fsh	0.551	0.525	0.536	0.514	0.551	0.514
CL fsh A	0.467	0.440	0.452	0.430	0.466	0.429
CL fsh B	0.394	0.367	0.379	0.357	0.393	0.356

Figure 31. Simulation testing results for olive ridley sea turtles (*Lepidochelys olivacea*) for the Western and Central Pacific Ocean. Interactions are shown in the upper panel; at-vessel mortalities are shown in the lower panel. Cell values and colours indicates the strength of reduction relative to the status quo (SQ) shown in the upper left corner as 1.00: red = no change; green = maximum reduction. Rows and columns specify mitigation options for deep and shallow set longlines, respectively. The table of mitigation scenarios and associated text in Section 4.5.3 provides a full explanation of the formatting of these mitigation scenario outputs.

Interactions

TUG WCPO	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.811	0.927	0.766	0.981	0.746
fsh	0.903	0.714	0.830	0.669	0.884	0.649
CL	0.809	0.620	0.736	0.575	0.790	0.555
A	0.912	0.723	0.839	0.678	0.893	0.658
B	0.836	0.647	0.764	0.602	0.817	0.582
fsh A	0.835	0.646	0.762	0.601	0.816	0.581
fsh B	0.777	0.588	0.704	0.543	0.758	0.523
CL A	0.757	0.569	0.685	0.524	0.738	0.504
CL B	0.712	0.524	0.640	0.479	0.693	0.459
CL fsh	0.755	0.566	0.682	0.521	0.736	0.501
CL fsh A	0.714	0.525	0.642	0.480	0.695	0.460
CL fsh B	0.679	0.491	0.607	0.445	0.660	0.425

At-vessel mortalities

TUG WCPO	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.953	0.970	0.935	0.997	0.932
fsh	0.863	0.816	0.834	0.799	0.861	0.796
CL	0.654	0.607	0.625	0.590	0.652	0.587
A	0.839	0.791	0.809	0.774	0.836	0.771
B	0.700	0.653	0.671	0.636	0.698	0.633
fsh A	0.729	0.682	0.700	0.665	0.727	0.662
fsh B	0.614	0.567	0.584	0.549	0.611	0.546
CL A	0.557	0.509	0.527	0.492	0.554	0.489
CL B	0.473	0.426	0.444	0.408	0.470	0.406
CL fsh	0.572	0.524	0.542	0.507	0.569	0.504
CL fsh A	0.491	0.443	0.461	0.426	0.488	0.423
CL fsh B	0.421	0.374	0.392	0.356	0.418	0.353

Figure 32. Simulation testing results for green sea turtles (*Chelonia mydas*) for the Western and Central Pacific Ocean. Interactions are shown in the upper panel; at-vessel mortalities are shown in the lower panel. Cell values and colours indicates the strength of reduction relative to the status quo (SQ) shown in the upper left corner as 1.00: red = no change; green = maximum reduction. Rows and columns specify mitigation options for deep and shallow set longlines, respectively. The table of mitigation scenarios and associated text in Section 4.5.3 provides a full explanation of the formatting of these mitigation scenario outputs.

5 Recommendations for Further Work

5.1 First Workshop Recommendations

Participants outlined several ideas for further work under the following headings: modelling, gear characteristics and data, mapping, data access, preparations for the next workshop.

5.1.1 *Modelling*

- Develop a baseline and then identify which mitigation scenarios to test (for example, 2 bait types and 4 hook categories);
- Circulate a list of mitigation scenarios to test for comment within one month of the first workshop; and
- Better inform the set-level model by including primary production in the model, or using water depth as a proxy for distance to nearest point of land (and/or shallow seamounts that may be important habitat for turtles (Allain et al. 2008).

5.1.2 *Gear characteristics and data*

- Undertake more work on understanding which hooks are/were fished (i.e. formulate an accurate master list) and what their key dimensions are (perhaps by means of a national survey or other types of gear research);
- Develop a variable that better represents the amount of daylight during which the hooks are being fished (use existing algorithms if possible); and
- Provide a better overall/general characterization of the data for the second workshop and/or the final report.

5.1.3 *Mapping*

- Develop at least one alternative turtle relative abundance surface to run as a sensitivity test;
- Update the maps with the latest tracking data
- Obtain expert review of the maps;
- Investigate available data on juvenile dispersal in the Pacific (take advantage of some ongoing work); and
- Use existing observer data and the table of turtle sizes in this report to develop distribution maps of life stages by species.

5.1.4 *Data Access*

- Cooperate with IAC to develop a specific data request with which to approach Latin American countries about participating and contributing data; and
- Consider more effective ways of seeking the participation of Spain, Indonesia and IATTC.

5.1.5 *Preparations for the Next Workshop*

- Focus the next meeting just prior to SC12 in Bali to review the results of simulation runs performed by SPC;
- Include a qualitative comparison between the parameters/effects estimated in our models and parameters/effects found in other studies worldwide (requires a review of existing

studies to be compiled for use at the meeting). This review should include a consideration of effects on target species catch. E. Gilman and S. Nicol offered to help with this literature review;

- Prepare workshop graphics for ease of viewing (e.g. avoid small fonts); and
- Consider whether there are opportunities for collaborative work on national datasets (either SPC travels, or participants are invited to Nouméa) prior to the next workshop.

5.2 Response to First Workshop Recommendations

5.2.1 *Modelling*

A list of 51 mitigation scenarios were developed and circulated for comment well before the second workshop; subsequently, another nine scenarios were formulated to explore further combinations of mitigation involving use of both large circle hooks and finfish bait for all shallow-set fisheries. A sensitivity test was prepared to substitute primary productivity for sea-surface temperature as a predictor of sea turtle habitat preferences by species.

5.2.2 *Gear characteristics and data*

WCPFC and SPC were unable to gather more information on the key properties of hook types currently in use by Pacific longline fisheries. This remains an important long-term research goal. Further work was undertaken to standardize variables such as soak time and time of day of the set relative to daylight and the revised variables were tested in the second workshop (see Section 4.1.2). A more extensive effort was made to characterize and summarize the available data for the second workshop (see Section 3.1).

5.2.3 *Mapping*

The relative abundance surfaces prepared in the first workshop were revised through an expert-judgement (Delphi) survey involving a number of recognized regional sea turtle experts. This survey was intended to update the maps with the latest available information (tracks, juvenile dispersal and other) without necessitating access to raw research data (as this is often problematic). For comparison, an alternative approach involving applying oceanographic variables as indicators of preferred sea turtle habitat was used, and this provides a basis for comparison with the expert judgement relative abundance surfaces. In addition, there was liaison with a research team at IFREMER and CLS working on model of sea turtle juvenile dispersal and their preliminary results were presented to the second workshop (Section 4.4.3).

As suggested, SPC applied Table 4 to existing observer data to produce species-specific maps by sea turtle life stage. These maps are presented as proportion by life stage in each 5x5 cell in *Annexes H-K*. Participants noted that there may be a bias against adult sea turtle measurement records as these individuals may not be brought onboard (and thus cannot be measured). It was noted that the Hawaii observer data provided for this workshop appears not to include sea turtle measurements but this was corrected and included in the maps (*Annexes H-K*). Participants were referred to Figures 16, 18, 20 and 22 for maps showing the locations of sea turtle nesting sites.

5.2.4 *Data Access*

The WCPFC Secretariat discovered that Japan held additional observer data for the Eastern Pacific and these data were requested, provided and incorporated into the database. Attempts to obtain other data for the Eastern Pacific were fruitless, although we did not try working in collaboration with IAC and acknowledge that that may have been useful. However, longline observer data in the Eastern Pacific seems very limited and thus it appears to be more an issue relating to lack of data rather than access to data. For the Western and Central Pacific, in particular Indonesia, according to the understanding of the WCPFC Secretariat and SPC, Indonesia does not hold any observer data for the WCPO. Indonesia currently conducts port sampling to supplement at-sea logbook records, but as sea turtles are not landed in port, catch records based on port sampling are expected to be scant.

5.2.5 *Preparations for the Next Workshop*

SPC received permission from Chinese Taipei and Japan to re-run the set-level model on the corrected Chinese Taipei dataset. This obviated the need to convene a short session in the margins of the WCPFC SC12 meeting. The results of the corrected set-level model were presented to SC12. The requested review of the literature was conducted by E. Gilman and presented to the second workshop. The request to prepare workshop graphics for better readability was taken into consideration for the second workshop. No requests were received or opportunities identified for collaborative work on national datasets, however, WCPFC and SPC wish to thank Chinese Taipei and Japan for their excellent cooperation before, between and during the workshops.

5.3 Second Workshop Recommendations

5.3.1 Observer data collection

The workshop agreed that one of the best approaches to obtaining high quality data for similar analyses in future is to ensure data collection protocols for turtle interactions with fisheries, and those describing the associated fishing effort, are standardised.

The workshop recommended that the WCPFC Regional Observer Programme observer data collection be improved with regard to:

- data on bait and hook types; and
- better species identifications (e.g. assign a data quality code based on factors such as whether there was photo-validation of at-vessel interactions, whether the identification was based on onboard examination, and the time of day of the sighting).

The workshop recommended that the WCPFC Regional Observer Programme Minimum Data Standards and Fields for observer data collection be updated to include:

- measurement of hooks for minimum width (due to variation between manufacturers);
- recording changes in bait use within and between sets;
- describing fully the terminal tackle on which any turtle is caught (hook number, hook type, hook size, branch line material); and
- a complete description of all fishing gear left attached to the turtle (length of line, material and type e.g. hook, branchline).

For all of these improvements additional training and materials for observers are likely needed.

The workshop recommended that observers be tasked to collect unambiguous information on the condition of turtles at release and their precise fate. This would require improved training on this topic for observers which is standardised across the region. There is also the associated need for scientists to have better access to the meta-data describing how data on condition and fate are collected so as to improve the analysis of information on fate of turtles and their condition.

The workshop recommended that those curating observer data sets be tasked to assess records of unknown turtle fate and condition to determine if they could be retrospectively reclassified to a known category in an unbiased manner. Any such reclassifications should be clearly described in the associated meta-data.

5.3.2 Habitat studies

The workshop recommended that better data on the temporal and spatial partitioning of sea turtle habitat by life stage be collected and modelled. The synthesis of such data should incorporate a broad range of appropriate modelling frameworks including individual based models.

The workshop recommended that observers be trained to attach satellite tags to, and collect biological samples from, turtles released post-vessel interactions to support the collection of better data on turtle ecology.

5.3.3 Future additional analyses

The workshop recommended that where new mitigation strategies are being investigated that such research address the full range of impacts of the potential changes to ensure a holistic perspective on the effect of such changes, e.g. the impact on target and bycatch species catch rates.

The workshop noted that future analyses would need to consider different historic fate/condition assessment protocols in deciding which response variables to use in the assessment of interactions and mortalities.

5.3.4 Co-operation with other initiatives

The workshop noted opportunities for collaboration with IAC, the WCPFC's Bycatch Management Information System (BMIS), Joint Tuna RFMO Bycatch Working Group, SWOT and the IUCN Marine Turtle Specialist Group (MTSG) in ongoing research into the effects of fishing interactions on sea turtles.

The workshop encouraged IAC, BMIS, Joint Tuna RFMO Bycatch Working Group, SWOT and IUCN MTSG to consider the results of the workshops and the chair committed to ensuring that those organisations received the results of the workshop directly. The workshop noted that the Joint Tuna RFMO Bycatch Working Group might consider how such analyses could be facilitated in other ocean basins. Such efforts are considered to be particularly important for species with populations which span ocean basins.

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Annex A. First Workshop Participants List

First Name	Last Name	Country/Organization	email
Keith	Bigelow	USA	keith.bigelow@noaa.gov
Chris	Boggs	USA	christofer.boggs@noaa.gov
Jerome	Bourjea	EU	Jerome.Bourjea@ifremer.fr
Veronica	Caceres	IAC	veronica@iacseaturtle.org
Sylvain	Caillot	SPC	SylvainC@spc.int
Shelley	Clarke	WCPFC/ABNJ	shelley.clarke@wcpfc.int
Paul	Dalzell	WPRFMC	paul.dalzell@wpcouncil.org;
Andres	Domingo	Uruguay	dimanchester@gmail.com
Rini	Ghosh	USA	rini.ghosh@noaa.gov
Bruno	Giffoni	Brazil	bruno@tamar.org.br
Eric	Gilman	ABNJ Consultant	FisheriesResearchGroup@gmail.com
Tuikolonga	Halafihi	Tonga	supi64t@gmail.com
Hsiang-Wen (Julia)	Huang	Chinese Taipei	julia@ntou.edu.tw
Asuka	Ishizaki	WPRFMC	asuka.ishizaki@wpcouncil.org
David	Itano	ISSF	daveitano@gmail.com
Emma	Kabua	RMI	emmakabua@gmail.com;
Irene	Kelly	USA	irene.kelly@noaa.gov;
Hiroshi	Minami	Japan	hminami@affrc.go.jp
Berry	Muller	RMI	bmuller@mimra.com
Simon	Nicol	Australia	Simon.Nicol@agriculture.gov.au
Thomas	Peatman	SPC	thomasp@spc.int;
Bradley Naiten	Phillip	FSM	bradley.phillip@norma.fm
Saiasi	Sarua	Cook Islands	s.sarau@mmr.gov.ck
Ratu Apenisa	Sauturaga	Fiji	sauturaga.apenisa@gmail.com
Kitty	Simonds	WPRFMC	kitty.simonds@noaa.gov
Catherine	Siota	SPREP	catherines@sprep.org
Yonat	Swimmer	USA	yonat.swimmer@noaa.gov
Asterio	Takashi	Palau	astertakasi23@gmail.com
Laitia	Tamata	WWF	ltamata@wwfpacific.org.fj
Thomas	Usu	Papua New Guinea	tusu@fisheries.gov.pg
Lotus	Vermeer	Palau	lvermeer@tnc.org

Annex B. Second Workshop Participants List

First Name	Last Name	Country/Organization	email
Keith	Bigelow	USA	keith.bigelow@noaa.gov
Chris	Boggs	USA	christofer.boggs@noaa.gov
Jerome	Bourjea	EU	Jerome.Bourjea@ifremer.fr
Veronica	Caceres	IAC	veronica@iacseaturtle.org
Sylvain	Caillot	SPC	SylvainC@spc.int
Shelley	Clarke	WCPFC/ABNJ	shelley.clarke@wcpfc.int
Andrés	Domingo	Uruguay	dimanchester@gmail.com
Fernando	Fiedler	Brazil	fnfiedler@hotmail.com
Martin	Finau	Tonga	finau.martin@gmail.com
Rini	Ghosh	USA	rini.ghosh@noaa.gov
Eric	Gilman	Palau	EricLGilman@gmail.com
Asuka	Ishizaki	WPRFMC	asuka.ishizaki@wpcouncil.org
David	Itano	ISSF	daveitano@gmail.com
Sekonaia	Naicovitabua	Fiji	naicovitabua.sekonaia@Gmail.com
Philipp	Neubauer	Dragonfly	philipp@dragonfly.co.nz
Kei	Okamoto	Japan	keiokamoto@fra.affrc.go.jp
Kazuhiro	Oshima	Japan	oshimaka@affrc.go.jp
Thomas	Peatman	SPC	thomasp@spc.int
Bradley Naiten	Phillip	FSM	bradley.phillip@norma.fm
Saiasi	Sarua	Cook Islands	s.sarau@mmr.gov.ck
Ratu Apenisa	Sauturaga	Fiji	sauturaga.apenisa@gmail.com
Kitty	Simonds	WPRFMC	kitty.simonds@noaa.gov
Catherine	Siota	SPREP	cagsiota@yahoo.com.au
Neville	Smith	SPC	nevilleS@spc.int
Yonat	Swimmer	USA	yonat.swimmer@noaa.gov
Asterio	Takashi	Palau	astertakasi23@gmail.com
Laitia	Tamata	WWF	ltamata@wwfpacific.org.fj
Feng	Wu	China	fwu@shou.edu.cn

Annex C. Condition, fate and biological data for sea turtle catches in the second workshop database by year and species.
Species codes: DKK (*Dermochelys coriacea*), FBT (*Natator depressus*), KEZ (*Chelonia agassizii*), LKV (*Lepidochelys olivacea*), TTH (*Eretmochelys imbricata*), TTL (*Caretta caretta*), TTX (Unidentified turtle species), TUG (*Chelonia mydas*). Please see *Annexes H-K* for distribution of sea turtles by life stage.

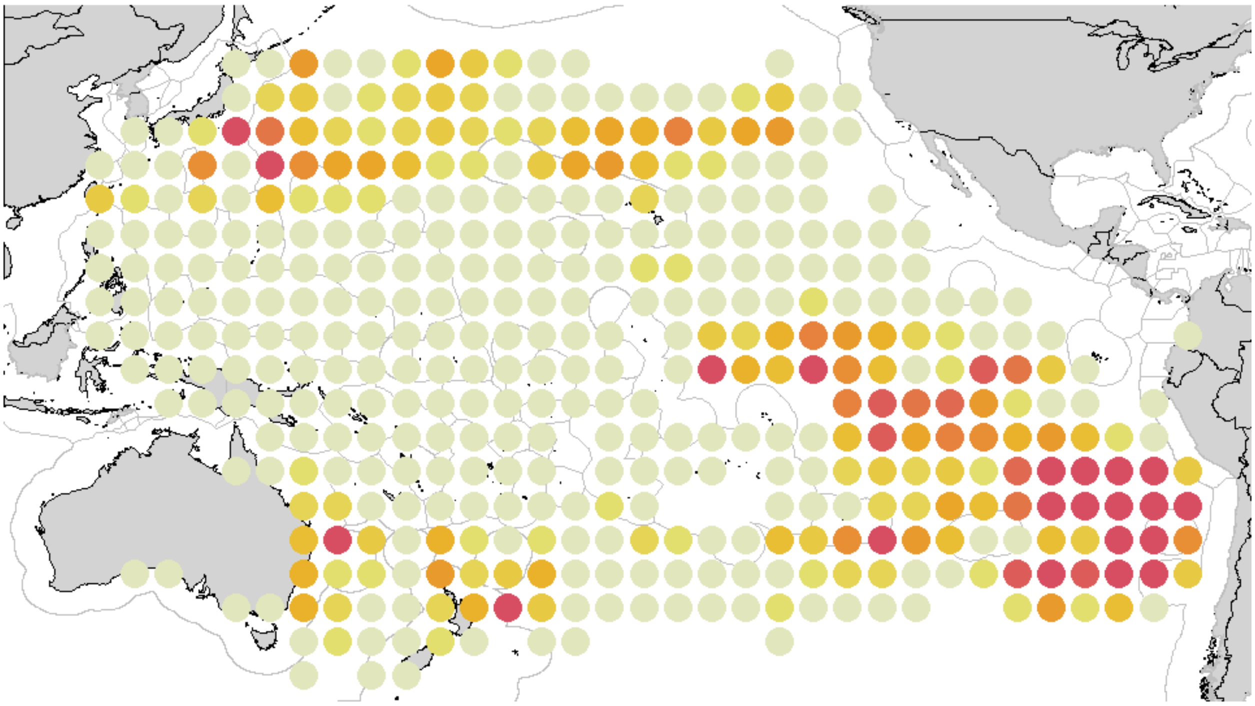
YY	sp_code	Cond_Alive	Cond_Unknown	Cond_Dead	Fate_Discarded	Fate_Retained	Fate_Escaped	Fate_Unknown	With_measure	No_measure	Sex_Male	Sex_Female	Sex_Indeterminate	Sex_Unknown	%_adult	%_juvenile	%_intermediate	%_unknown
1993	DKK	1	0	0	1	0	0	0	0	1	0	0	0	1	0.0	0.0	0.0	100.0
1994	DKK	0	8	0	8	0	0	0	1	7	0	0	0	8	0.0	0.0	12.5	87.5
1995	DKK	0	4	0	4	0	0	0	1	3	0	0	0	4	0.0	25.0	0.0	75.0
1996	DKK	0	9	0	9	0	0	0	0	9	0	0	0	9	0.0	0.0	0.0	100.0
1997	DKK	0	12	0	12	0	0	0	0	12	0	0	0	12	0.0	0.0	0.0	100.0
1998	DKK	2	5	0	7	0	0	0	1	6	1	0	0	6	0.0	14.3	0.0	85.7
1999	DKK	2	2	0	4	0	0	0	1	3	1	0	0	3	0.0	25.0	0.0	75.0
2000	DKK	0	10	0	10	0	0	0	0	10	0	0	0	10	0.0	0.0	0.0	100.0
2001	DKK	2	2	0	4	0	0	0	0	4	0	0	0	4	0.0	0.0	0.0	100.0
2002	DKK	1	5	0	5	0	1	0	1	5	0	0	0	6	0.0	16.7	0.0	83.3
2003	DKK	5	1	0	6	0	0	0	0	6	0	0	0	6	0.0	0.0	0.0	100.0
2004	DKK	15	0	2	16	0	1	0	5	12	3	1	0	13	0.0	11.8	17.6	70.6
2005	DKK	18	0	0	18	0	0	0	2	16	2	0	0	16	0.0	5.6	5.6	88.9
2006	DKK	12	2	3	17	0	0	0	3	14	2	2	0	13	0.0	17.6	0.0	82.4
2007	DKK	10	1	0	10	1	0	0	0	11	0	0	0	11	0.0	0.0	0.0	100.0
2008	DKK	7	1	0	8	0	0	0	1	7	0	0	0	8	0.0	12.5	0.0	87.5
2009	DKK	18	2	0	19	0	0	1	0	20	1	0	0	19	0.0	0.0	0.0	100.0
2010	DKK	15	2	2	16	2	0	1	7	12	0	3	0	16	5.3	26.3	5.3	63.2
2011	DKK	30	1	4	33	2	0	0	12	23	2	0	0	33	2.9	25.7	5.7	65.7
2012	DKK	15	8	3	22	3	0	1	7	19	3	0	0	23	0.0	23.1	3.8	73.1
2013	DKK	38	5	2	36	2	0	7	8	37	1	1	0	43	2.2	11.1	4.4	82.2
2014	DKK	29	5	6	34	1	0	5	5	35	1	0	0	39	2.5	7.5	2.5	87.5
2015	DKK	2	1	1	2	0	0	2	1	3	0	0	1	3	0.0	25.0	0.0	75.0
2005	FBT	0	0	1	1	0	0	0	1	0	1	0	0	0	0.0	0.0	100.0	0.0
2006	FBT	0	0	1	1	0	0	0	1	0	0	1	0	0	0.0	0.0	100.0	0.0
2007	FBT	5	0	0	5	0	0	0	5	0	0	0	2	3	0.0	0.0	100.0	0.0
2010	FBT	1	0	0	1	0	0	0	0	1	0	1	0	0	0.0	0.0	0.0	100.0
2011	FBT	1	0	0	1	0	0	0	0	1	0	0	0	1	0.0	0.0	0.0	100.0
2012	FBT	1	0	0	1	0	0	0	1	0	1	0	0	0	0.0	0.0	100.0	0.0
2013	FBT	1	0	0	1	0	0	0	1	0	1	0	0	0	0.0	0.0	100.0	0.0
2014	FBT	1	0	4	5	0	0	0	2	3	0	3	0	2	0.0	0.0	40.0	60.0
2011	KEZ	1	0	0	0	0	0	1	1	0	0	0	1	0	0.0	0.0	100.0	0.0
1994	LKV	0	3	0	3	0	0	0	2	1	0	0	0	3	0.0	0.0	66.7	33.3
1995	LKV	5	4	0	9	0	0	0	7	2	0	0	0	9	0.0	0.0	77.8	22.2
1996	LKV	2	9	0	11	0	0	0	11	0	1	0	0	10	0.0	0.0	100.0	0.0
1997	LKV	3	3	1	7	0	0	0	4	3	0	0	0	7	0.0	0.0	57.1	42.9
1998	LKV	7	5	3	15	0	0	0	3	12	7	0	0	8	0.0	0.0	20.0	80.0
1999	LKV	4	8	0	12	0	0	0	12	0	0	4	0	8	0.0	0.0	100.0	0.0
2000	LKV	0	10	2	12	0	0	0	12	0	1	1	0	10	0.0	0.0	100.0	0.0
2001	LKV	0	10	0	10	0	0	0	10	0	0	0	0	10	0.0	0.0	100.0	0.0
2002	LKV	0	7	0	7	0	0	0	7	0	0	0	0	7	0.0	0.0	100.0	0.0
2003	LKV	2	2	2	5	1	0	0	6	0	1	2	0	3	0.0	0.0	100.0	0.0
2004	LKV	18	0	17	33	2	0	0	32	3	7	9	2	17	0.0	0.0	91.4	8.6
2005	LKV	9	0	4	12	1	0	0	11	2	0	2	2	9	0.0	0.0	84.6	15.4
2006	LKV	13	1	17	30	1	0	0	26	5	3	11	0	17	0.0	0.0	83.9	16.1
2007	LKV	29	5	31	57	8	0	0	49	16	16	15	9	25	0.0	0.0	75.4	24.6
2008	LKV	34	1	22	53	2	1	1	46	11	14	23	1	19	0.0	0.0	80.7	19.3
2009	LKV	18	9	21	47	0	0	1	40	8	4	22	7	15	0.0	0.0	83.3	16.7
2010	LKV	32	0	30	34	1	1	26	56	6	9	20	0	33	0.0	0.0	90.3	9.7
2011	LKV	15	2	43	43	2	0	15	55	5	6	20	10	24	0.0	0.0	91.7	8.3
2012	LKV	28	3	70	83	1	0	17	94	7	39	15	6	41	0.0	0.0	93.1	6.9
2013	LKV	37	2	55	72	0	0	22	90	4	34	30	3	27	0.0	0.0	95.7	4.3
2014	LKV	34	3	60	64	0	1	32	86	11	30	18	7	42	0.0	0.0	88.7	11.3
2015	LKV	2	1	4	4	0	0	3	3	4	2	1	1	3	0.0	0.0	42.9	57.1
1996	TTH	1	0	0	1	0	0	0	1	0	0	0	0	1	0.0	100.0	0.0	0.0
1998	TTH	1	0	1	2	0	0	0	0	2	0	0	0	2	0.0	0.0	0.0	100.0
2000	TTH	5	0	0	5	0	0	0	1	4	4	1	0	0	0.0	20.0	0.0	80.0
2002	TTH	3	0	0	3	0	0	0	2	1	0	0	0	3	0.0	66.7	0.0	33.3
2003	TTH	0	0	1	1	0	0	0	1	0	0	0	0	1	0.0	0.0	100.0	0.0
2004	TTH	1	0	1	1	1	0	0	1	1	1	0	0	1	0.0	50.0	0.0	50.0
2005	TTH	0	0	2	1	1	0	0	2	0	1	0	0	1	0.0	100.0	0.0	0.0
2006	TTH	0	1	2	3	0	0	0	2	1	0	1	0	2	0.0	66.7	0.0	33.3
2007	TTH	3	0	0	3	0	0	0	2	1	1	0	0	2	33.3	33.3	0.0	33.3
2008	TTH	5	0	4	8	0	1	0	7	2	1	4	0	4	22.2	55.6	0.0	22.2
2009	TTH	2	0	1	3	0	0	0	2	1	0	1	0	2	33.3	33.3	0.0	33.3
2010	TTH	2	0	4	6	0	0	0	6	0	1	1	0	4	33.3	66.7	0.0	0.0
2011	TTH	3	3	0	6	0	0	0	4	2	0	1	0	5	16.7	33.3	16.7	33.3
2012	TTH	6	2	6	14	0	0	0	12	2	4	3	1	6	0.0	57.1	28.6	14.3
2013	TTH	8	2	4	14	0	0	0	12	2	5	5	0	4	0.0	78.6	7.1	14.3
2014	TTH	3	2	5	10	0	0	0	6	4	0	3	0	7	0.0	60.0	0.0	40.0
2015	TTH	3	1	0	4	0	0	0	3	1	1	2	0	1	0.0	75.0	0.0	25.0

Annex C. (continued)

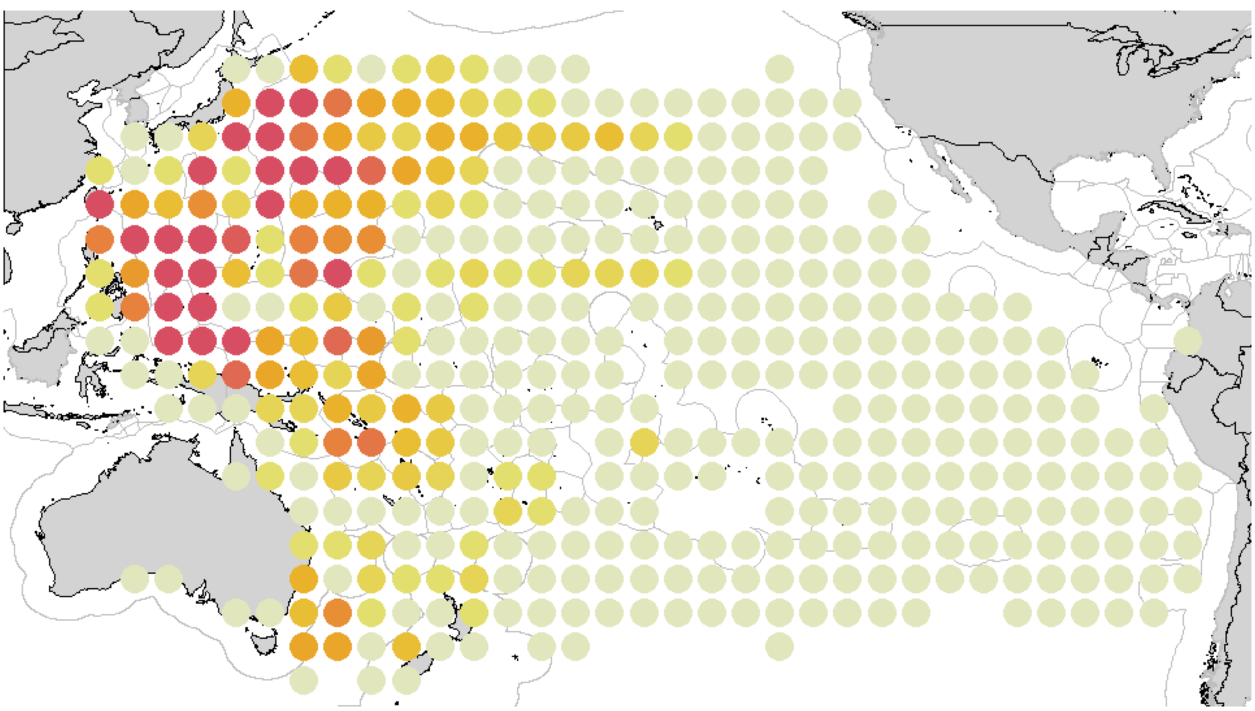
YY	sp_code	Cond_Alive	Cond_Unknown	Cond_Dead	Fate_Discarded	Fate_Retained	Fate_Escaped	Fate_Unknown	With_measure	No_measure	Sex_Male	Sex_Female	Sex_Indeterminate	Sex_Unknown	%_adult	%_juvenile	%_intermediate	%_unknown
1995	TTL	0	19	0	19	0	0	0	19	0	0	0	0	19	0.0	89.5	10.5	0.0
1996	TTL	1	28	0	29	0	0	0	24	5	0	0	0	29	0.0	72.4	10.3	17.2
1997	TTL	0	22	0	22	0	0	0	21	1	0	0	0	22	0.0	77.3	18.2	4.5
1998	TTL	1	48	0	49	0	0	0	41	8	0	1	0	48	0.0	71.4	12.2	16.3
1999	TTL	0	21	0	21	0	0	0	18	3	0	0	0	21	0.0	66.7	19.0	14.3
2000	TTL	0	22	0	22	0	0	0	22	0	0	0	0	22	0.0	81.8	18.2	0.0
2001	TTL	0	6	1	7	0	0	0	6	1	0	0	0	7	0.0	85.7	0.0	14.3
2002	TTL	2	4	0	6	0	0	0	4	2	0	1	0	5	0.0	66.7	0.0	33.3
2004	TTL	6	0	0	6	0	0	0	3	3	1	0	0	5	0.0	50.0	0.0	50.0
2005	TTL	14	1	0	15	0	0	0	12	3	0	3	0	12	0.0	73.3	6.7	20.0
2006	TTL	18	1	2	21	0	0	0	17	4	0	1	0	20	0.0	71.4	9.5	19.0
2007	TTL	21	0	0	21	0	0	0	19	2	2	1	0	18	0.0	38.1	52.4	9.5
2008	TTL	6	0	5	9	1	0	1	6	5	2	1	0	8	0.0	54.5	0.0	45.5
2009	TTL	5	0	0	5	0	0	0	3	2	1	0	0	4	0.0	40.0	20.0	40.0
2010	TTL	15	0	3	16	1	0	1	12	6	0	2	0	16	5.6	55.6	5.6	33.3
2011	TTL	25	4	1	20	0	0	10	25	5	1	3	3	23	0.0	63.3	20.0	16.7
2012	TTL	22	22	8	50	2	0	0	24	28	7	6	3	36	0.0	42.3	3.8	53.8
2013	TTL	20	11	9	39	1	0	0	24	16	7	5	0	28	2.5	50.0	7.5	40.0
2014	TTL	100	13	14	46	5	1	75	73	54	9	15	4	99	1.6	45.7	10.2	42.5
2015	TTL	13	4	0	4	0	0	13	9	8	5	0	3	9	0.0	47.1	5.9	47.1
1989	TTX	0	1	0	0	1	0	0	0	1	0	0	0	1	0.0	0.0	0.0	100.0
1990	TTX	0	1	0	0	1	0	0	0	1	0	0	0	1	0.0	0.0	0.0	100.0
1991	TTX	0	1	0	1	0	0	0	0	1	0	0	1	0	0.0	0.0	0.0	100.0
1993	TTX	4	1	1	6	0	0	0	1	5	3	0	0	3	0.0	0.0	16.7	83.3
1994	TTX	13	3	3	19	0	0	0	12	7	2	6	0	11	0.0	0.0	63.2	36.8
1995	TTX	6	3	2	11	0	0	0	1	10	3	0	0	8	0.0	0.0	9.1	90.9
1996	TTX	2	2	0	4	0	0	0	0	4	1	0	0	3	0.0	0.0	0.0	100.0
1997	TTX	4	3	1	7	1	0	0	3	5	1	0	1	6	0.0	0.0	37.5	62.5
1998	TTX	3	2	0	5	0	0	0	1	4	0	0	0	5	0.0	0.0	20.0	80.0
1999	TTX	4	0	1	4	1	0	0	1	4	0	1	0	4	0.0	0.0	20.0	80.0
2001	TTX	7	2	5	14	0	0	0	8	6	0	1	0	13	0.0	0.0	57.1	42.9
2002	TTX	6	0	6	7	5	0	0	8	4	2	0	3	7	0.0	0.0	66.7	33.3
2003	TTX	4	0	3	5	2	0	0	3	4	0	1	0	6	0.0	0.0	42.9	57.1
2004	TTX	5	0	3	6	2	0	0	6	2	2	0	0	6	0.0	0.0	75.0	25.0
2005	TTX	1	0	0	1	0	0	0	1	0	0	0	0	1	0.0	0.0	100.0	0.0
2006	TTX	9	1	27	37	0	0	0	34	3	26	6	0	5	0.0	0.0	91.9	8.1
2007	TTX	1	1	2	3	0	1	0	1	3	0	0	0	4	0.0	0.0	25.0	75.0
2008	TTX	0	0	1	0	1	0	0	1	0	0	0	0	1	0.0	0.0	100.0	0.0
2010	TTX	2	1	0	3	0	0	0	0	3	0	0	0	3	0.0	0.0	0.0	100.0
2011	TTX	11	1	2	3	0	0	11	10	4	4	0	2	8	0.0	0.0	71.4	28.6
2012	TTX	2	2	10	3	0	1	10	9	5	0	5	1	8	0.0	0.0	64.3	35.7
2013	TTX	12	2	18	7	0	0	25	19	13	15	1	1	15	0.0	0.0	59.4	40.6
2014	TTX	32	4	3	4	0	0	35	9	30	4	1	1	33	0.0	0.0	23.1	76.9
2015	TTX	1	0	3	0	0	0	4	0	4	0	0	0	4	0.0	0.0	0.0	100.0
1994	TUG	0	2	0	2	0	0	0	2	0	0	0	0	2	0.0	100.0	0.0	0.0
1995	TUG	4	0	0	4	0	0	0	1	3	0	0	0	4	0.0	25.0	0.0	75.0
1996	TUG	1	3	0	4	0	0	0	3	1	0	0	0	4	0.0	25.0	50.0	25.0
1997	TUG	1	0	0	1	0	0	0	0	1	0	0	0	1	0.0	0.0	0.0	100.0
1998	TUG	0	2	0	2	0	0	0	2	0	0	0	0	2	0.0	100.0	0.0	0.0
1999	TUG	7	3	0	10	0	0	0	6	4	0	1	0	9	0.0	60.0	0.0	40.0
2000	TUG	4	7	0	11	0	0	0	10	1	1	0	0	10	0.0	90.9	0.0	9.1
2001	TUG	1	1	0	2	0	0	0	1	1	0	0	0	2	0.0	50.0	0.0	50.0
2002	TUG	2	1	0	3	0	0	0	1	2	0	0	0	3	0.0	33.3	0.0	66.7
2003	TUG	1	0	2	2	1	0	0	3	0	1	1	0	1	0.0	100.0	0.0	0.0
2004	TUG	7	1	3	11	0	0	0	8	3	2	2	0	7	0.0	72.7	0.0	27.3
2005	TUG	12	0	3	14	1	0	0	7	8	1	3	0	11	6.7	40.0	0.0	53.3
2006	TUG	3	0	6	9	0	0	0	9	0	1	1	0	7	0.0	88.9	11.1	0.0
2007	TUG	6	0	8	12	2	0	0	12	2	0	5	1	8	0.0	78.6	7.1	14.3
2008	TUG	12	0	24	34	2	0	0	32	4	9	17	2	8	0.0	88.9	0.0	11.1
2009	TUG	4	0	7	11	0	0	0	10	1	1	0	3	7	0.0	90.9	0.0	9.1
2010	TUG	7	0	8	14	0	0	1	12	3	4	0	0	11	0.0	73.3	6.7	20.0
2011	TUG	13	3	15	20	11	0	0	30	1	3	3	2	23	29.0	58.1	9.7	3.2
2012	TUG	25	5	11	35	6	0	0	32	9	6	8	2	25	4.9	63.4	9.8	22.0
2013	TUG	32	5	25	54	6	0	2	52	10	24	12	1	25	3.2	77.4	3.2	16.1
2014	TUG	11	1	17	26	1	0	2	26	3	3	3	4	19	3.4	86.2	0.0	10.3
2015	TUG	3	3	3	8	0	0	1	6	3	1	1	0	7	0.0	55.6	11.1	33.3

Annex D. Effort maps by sector (see Section 3.2.2 for methodology)

Shallow-Swordfish

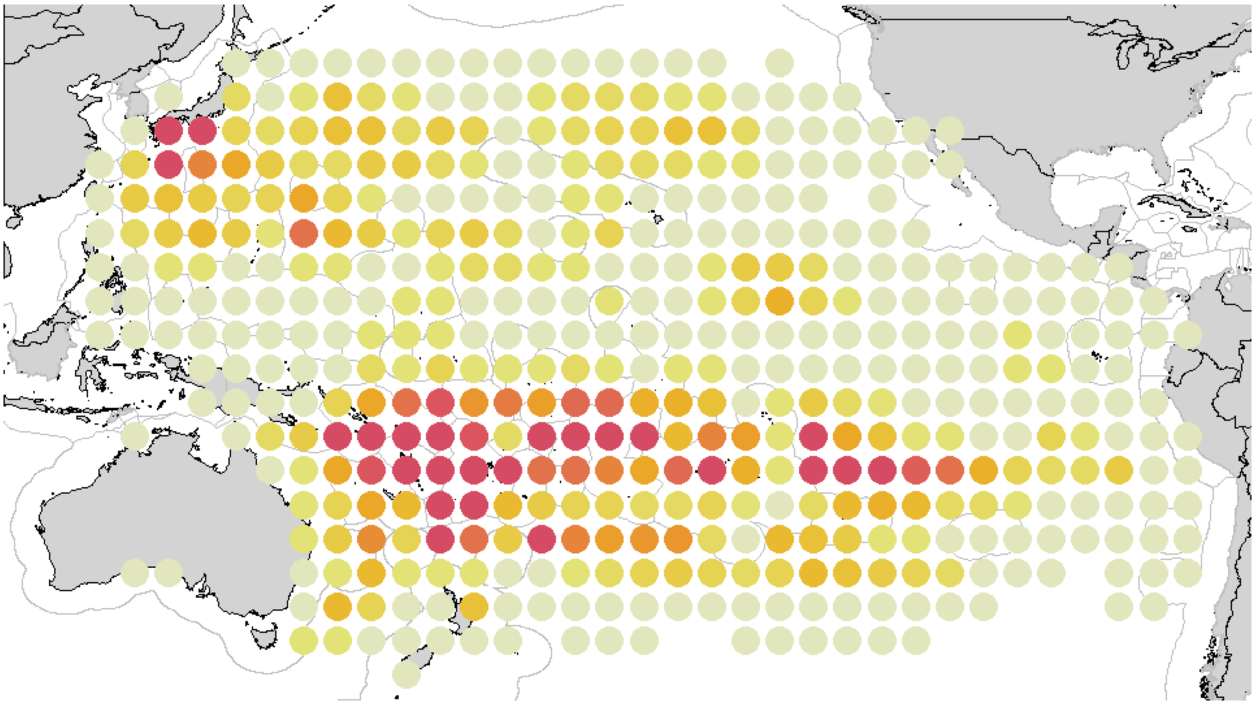


Shallow-Other

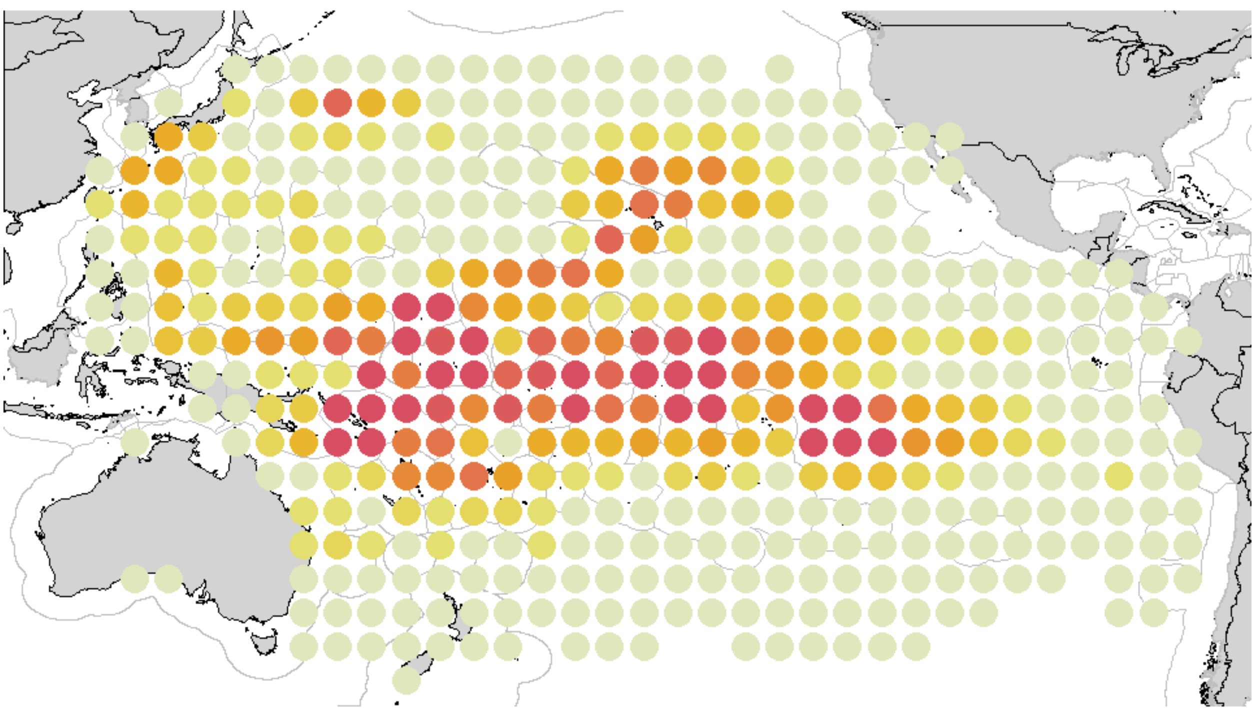


Annex D. (continued)

Deep-Albacore



Deep-Other



Annex E. Sea turtle bycatch mitigation regulatory history for the Hawaii and American Samoa pelagic longline fisheries[7].

Date Came into Effect	Action
1999-2004	A series of court-ordered closures and effort restrictions for the Hawaii-based longline fishery were implemented starting in December 1999. An emergency rule implementing a court order became effective in 2001, which prohibited shallow-set swordfish longlining north of the equator by vessels managed under the WPRFMC's Pelagics FMP and closed waters between 0° and 15°N from April through May of each year to longline fishing. The measures also instituted sea turtle handling requirements for all vessels using hooks to target pelagic species in the region's EEZ waters. The emergency rule (effective for 180 days) was extended once, and later implemented as a final rule in June 2002, remaining in place until 2004 when the swordfish fishery was reopened.
2 April 2004	Re-opened the shallow-set swordfish fishery, allowing 2,120 shallow-sets to be made annually by the Hawaii-based longline line fleet. Circle hooks and mackerel-type bait were required, along with other mitigation measures (see summary of current in effect measures, below) and a maximum annual limit on the number of interactions with sea turtles was set at 16 leatherbacks and 17 loggerheads. The rule also eliminated the closure between 0° and 15°N from April through May of each year to longline fishing.
15 December 2005	Owners and operators of vessels registered for use under longline general permits are required to attend protected species workshops annually. Owners and operators of vessels registered for use under longline general permits are required to carry and use dip nets, line clippers, and bolt cutters, and follow handling, resuscitation, and release requirements for incidentally hooked or entangled sea turtles. Extended the requirement to use circle hooks, mackerel-type bait and dehookers when shallow-setting north of the equator to include all longline vessels managed under the Pelagics FMP. These measures were adopted to obtain consistency with a 2004 Biological Opinion. As there are no general longline permit holders that fish for swordfish north of the equator, the measure had no effect other than to prevent longline permit holders from shifting to using a general permit to avoid sea turtle measures.
11 January 2010	Limit on number of shallow sets made per year was eliminated and loggerhead hard cap was increased from 17 to 46.
2011	Court order reinstates the 2004 sea turtle hard cap for the Hawaii longline shallow-set fishery.
23 September 2011	Specific gear configuration was implemented for American Samoa longline vessels longer than 40ft (12.2m) to ensure that hooks soak deeper than 100 m by requiring each float line to be at least 30 meters long, each branch line to be at least 10 meters long, and branch lines to be attached to the mainline at least 70 meters from any float line. This measure was intended to reduce green sea turtle interactions in the fishery.
5 November 2012	NMFS revised the limits for leatherback turtles from 16 to 26, and for loggerhead turtles from 17 to 34 for the Hawaii longline shallow-set fishery.

[7] This summary does not describe regulatory-required measures instituted for purposes other than managing sea turtle interactions, which might affect sea turtle catch and survival rates (e.g., Hawaii longline tuna fishery requirement to use only 'weak' circle hooks under the false killer whale take reduction plan, swordfish fishery option to night set to mitigate seabird bycatch).

Annex F. Absolute and relative increases in the probability of longline-sea turtle interactions under each combination of hook category and bait type for each sea turtle species (see notes below).

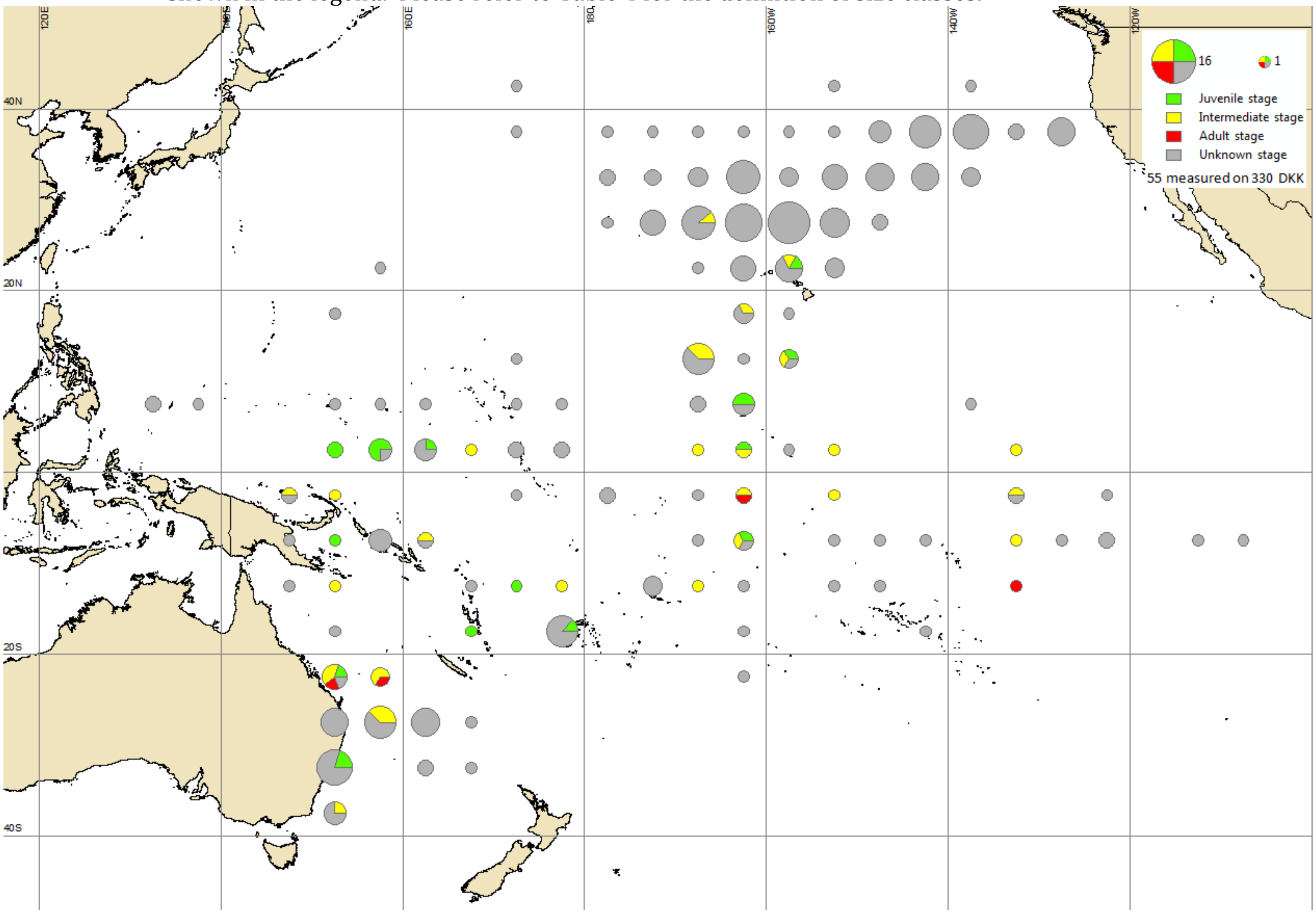
Hook category	Bait simple	Interaction probability	% increase in absolute terms	% increase in relative terms
Leatherback				
C-L	fsh	0.00359		
C-L	fsh-sqd	0.00556	0.20%	55%
C-S	fsh	0.00827		
C-S	fsh-sqd	0.01279	0.45%	55%
J-S	fsh	0.00847		
J-S	fsh-sqd	0.01311	0.46%	55%
J-S	sqd	0.04125	3.28%	387%
T-S	fsh	0.00569		
T-S	fsh-sqd	0.00882	0.31%	55%
T-S	sqd	0.02788	1.91%	390%
Loggerhead				
C-L	fsh	0.01092		
C-L	fsh-sqd	0.01690	0.60%	55%
C-S	fsh	0.02505		
C-S	fsh-sqd	0.03859	1.35%	54%
J-S	fsh	0.02567		
J-S	fsh-sqd	0.03954	1.39%	54%
J-S	sqd	0.12083	9.52%	371%
T-S	fsh	0.01730		
T-S	fsh-sqd	0.02671	0.94%	54%
T-S	sqd	0.08280	5.61%	379%
Green				
C-L	fsh	0.00028		
C-L	fsh-sqd	0.00043	0.02%	55%
C-S	fsh	0.00064		
C-S	fsh-sqd	0.00100	0.04%	55%
J-S	fsh	0.00066		
J-S	fsh-sqd	0.00102	0.04%	55%
J-S	sqd	0.00327	0.26%	395%
T-S	fsh	0.00044		
T-S	fsh-sqd	0.00069	0.02%	55%
T-S	sqd	0.00219	0.15%	395%
Olive ridley				
C-L	fsh	0.00022		
C-L	fsh-sqd	0.00034	0.01%	55%
C-S	fsh	0.00051		
C-S	fsh-sqd	0.00079	0.03%	55%
J-S	fsh	0.00052		
J-S	fsh-sqd	0.00081	0.03%	55%
J-S	sqd	0.00258	0.21%	395%
T-S	fsh	0.00035		
T-S	fsh-sqd	0.00054	0.02%	55%
T-S	sqd	0.00173	0.12%	395%

Note: % increases are for mixed fish and squid (fsh-sqd) and squid bait (sqd) relative to fish bait (fsh). Interaction probabilities were estimated with variables set at their median value for shallow setting (hooks set – 976 hooks, hbf – 4, SST – 18.9 C, distance – 481 nm)

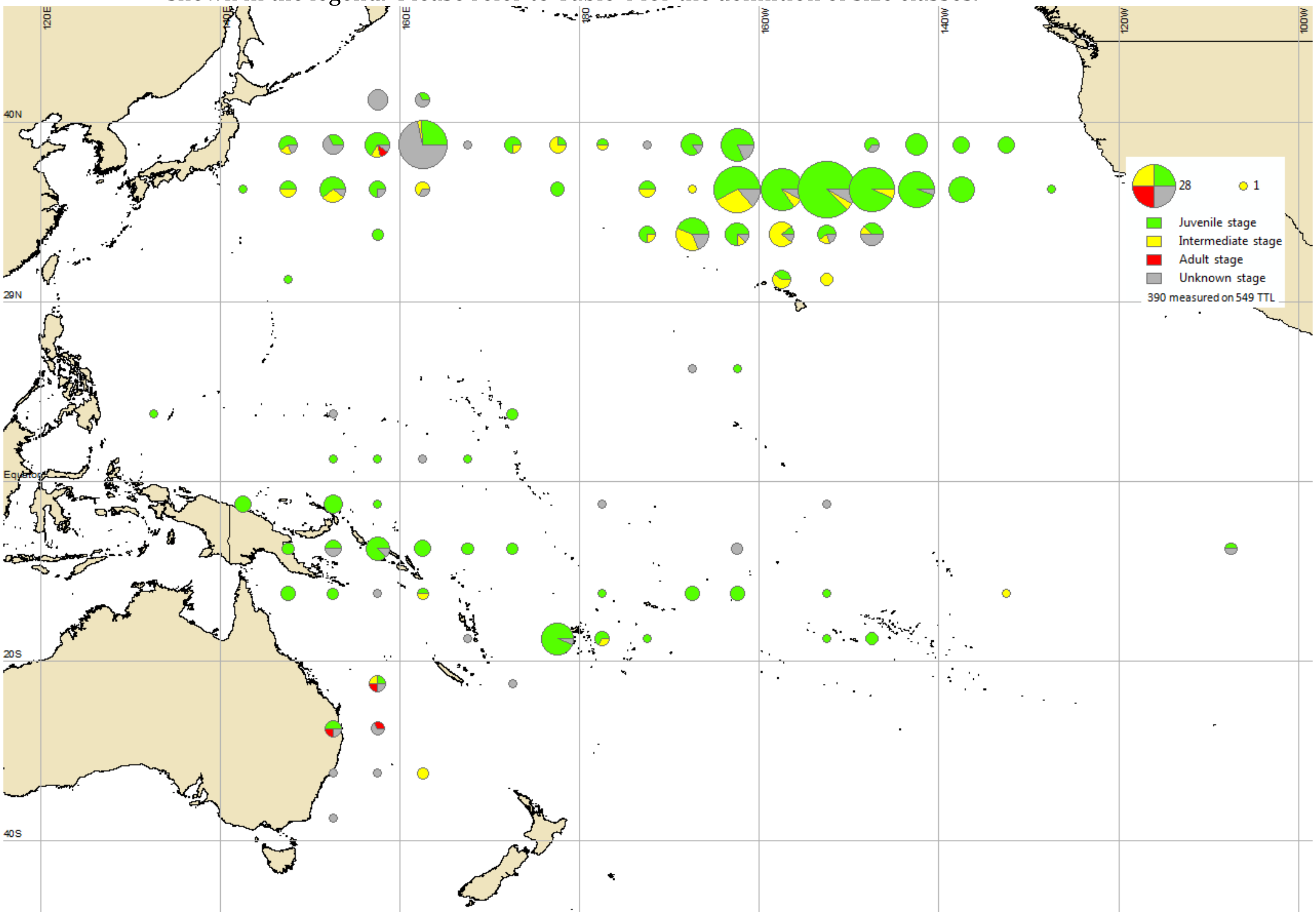
Annex G. Percentage of the distribution area and RMUs that falls within the WCPFC Convention Area for each sea turtle species considered in the workshop.
(The percentages refer to the non-white areas in Figures 17, 19, 21 and 23. Note that there is no defined western boundary of the WCPFC Convention Area but for the purposes of this table the calculations have included only areas east of 120°E.)

Species	Areas	Within WCPFC area
LEATHERBACK TURTLE	Distribution area	59.1%
	RMU 56	89.9%
	RMU 55	3.4%
OLIVE RIDLEY TURTLE	Distribution area	60.6%
	RMU 03	97.8%
	RMU 09	0.0%
	Overlap RMU 03/09	48.9%
LOGGERHEAD TURTLE	Distribution area	59.7%
	RMU 29	75.0%
	RMU 30	62.6%
	RMU 31	65.1%
GREEN TURTLE	Distribution area	66.0%
	RMU 34	7.8%
	RMU 35	100.0%
	RMU 36	100.0%
	RMU 37	100.0%
	RMU 38	100.0%
	RMU 39	100.0%
	RMU 40	85.7%
	RMU 41	100.0%

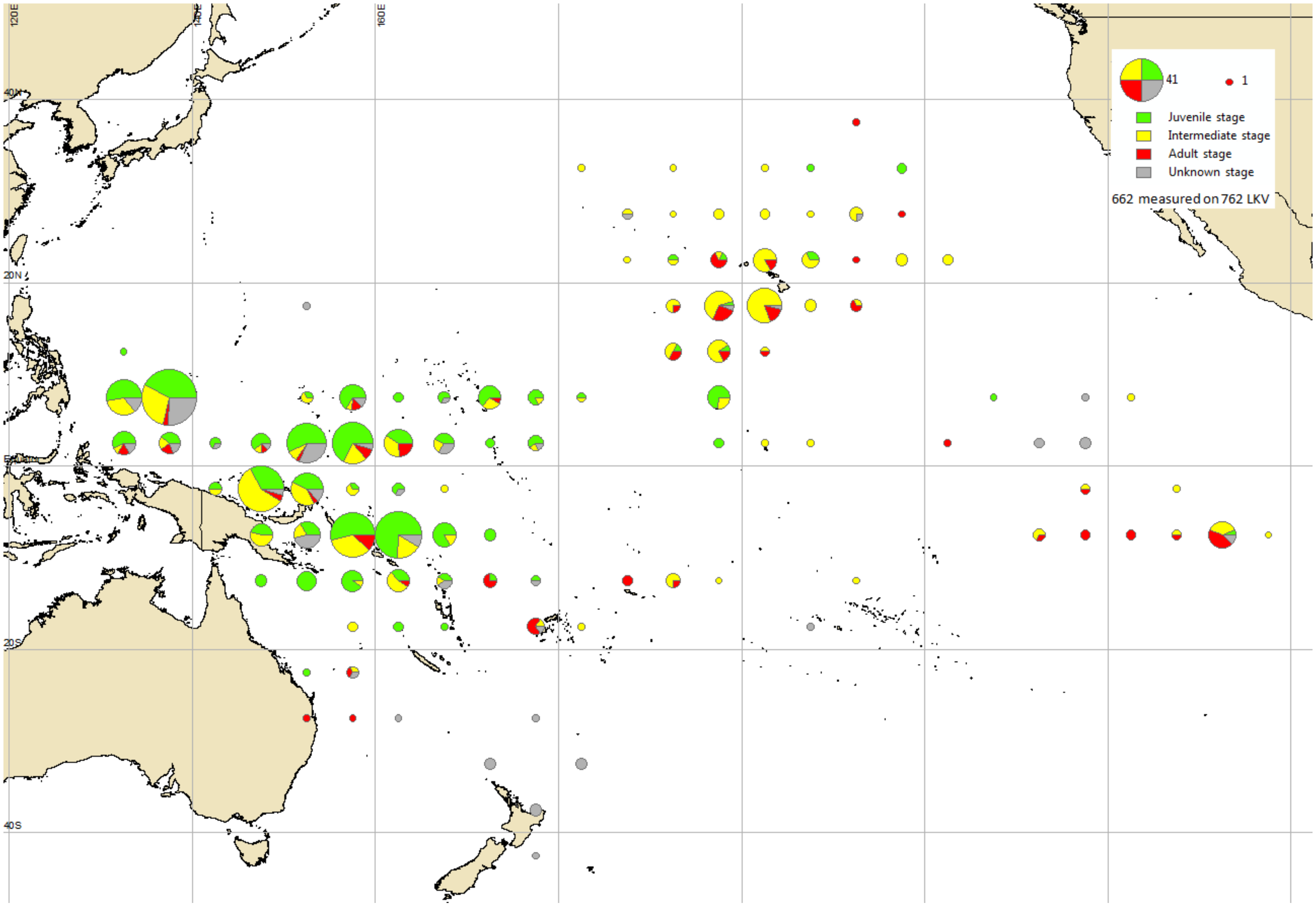
Annex H. **Maps by species and life stage for leatherback sea turtles (*Dermochelys coriacea*)** showing the proportion of individuals in each life stage in each 5x5 lat/lon cell. Juveniles are shown in green, adults in red and intermediate stage in yellow. The size of the circle represents the total number of individuals sampled with the scale shown in the legend. Please refer to Table 4 for the definition of size classes.



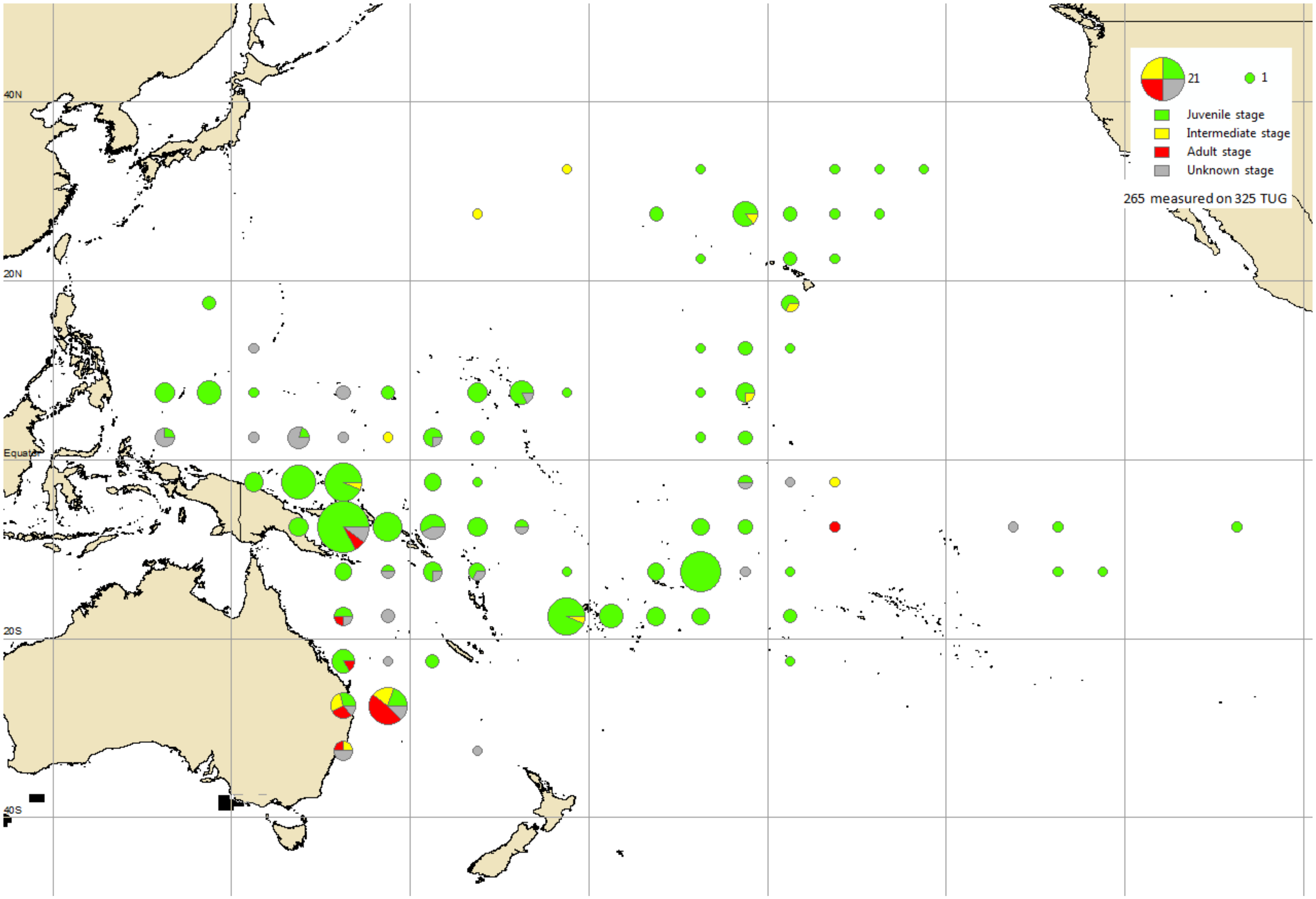
Annex I. **Maps by species and life stage for loggerhead sea turtles (*Caretta caretta*)** showing the proportion of individuals in each life stage in each 5x5 lat/lon cell. Juveniles are shown in green, adults in red and intermediate stage in yellow. The size of the circle represents the total number of individuals sampled with the scale shown in the legend. Please refer to Table 4 for the definition of size classes.



Annex J. **Maps by species and life stage for olive ridley sea turtles (*Lepidochelys olivacea*)** showing the proportion of individuals in each life stage in each 5x5 lat/lon cell. Juveniles are shown in green, adults in red and intermediate stage in yellow. The size of the circle represents the total number of individuals sampled with the scale shown in the legend. Please refer to Table 4 for the definition of size classes.



Annex K. **Maps by species and life stage for green sea turtles (*Chelonia mydas*)** showing the proportion of individuals in each life stage in each 5x5 lat/lon cell. Juveniles are shown in green, adults in red and intermediate stage in yellow. The size of the circle represents the total number of individuals sampled with the scale shown in the legend. Please refer to Table 4 for the definition of size classes.



Annex L. Simulation testing results for the Pacific Ocean

Interactions

Total Pacific-wide	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.847	0.953	0.816	0.937	0.753
fsh	0.920	0.768	0.873	0.737	0.858	0.673
CL	0.811	0.658	0.764	0.627	0.748	0.564
A	0.908	0.755	0.861	0.724	0.845	0.661
B	0.835	0.682	0.787	0.651	0.772	0.587
fsh A	0.845	0.692	0.798	0.661	0.782	0.598
fsh B	0.785	0.632	0.738	0.601	0.722	0.538
CL A	0.755	0.603	0.708	0.572	0.692	0.508
CL B	0.711	0.558	0.664	0.527	0.648	0.464
CL fsh	0.763	0.611	0.716	0.580	0.701	0.516
CL fsh A	0.718	0.565	0.670	0.534	0.655	0.470
CL fsh B	0.681	0.528	0.634	0.497	0.618	0.434

At-vessel mortalities

Total Pacific-wide	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.977	0.987	0.968	0.997	0.965
fsh	0.861	0.838	0.847	0.829	0.858	0.826
CL	0.637	0.614	0.624	0.605	0.634	0.602
A	0.821	0.798	0.808	0.789	0.818	0.786
B	0.678	0.655	0.664	0.646	0.674	0.643
fsh A	0.710	0.687	0.696	0.678	0.707	0.675
fsh B	0.589	0.566	0.576	0.558	0.586	0.554
CL A	0.528	0.505	0.515	0.496	0.525	0.493
CL B	0.440	0.417	0.426	0.408	0.437	0.405
CL fsh	0.551	0.528	0.537	0.519	0.548	0.516
CL fsh A	0.458	0.435	0.445	0.427	0.455	0.423
CL fsh B	0.385	0.361	0.371	0.353	0.381	0.349

Figure L1. Simulation testing results for all sea turtle species for the Pacific Ocean. Interactions are shown in the upper panel; at-vessel mortalities are shown in the lower panel. Cell values and colours indicates the strength of reduction relative to the status quo (SQ) shown in the upper left corner as 1.00: red = no change; green = maximum reduction. Rows and columns specify mitigation options for deep and shallow set longlines, respectively. The table of mitigation scenarios and associated text in Section 4.5.3 provides a full explanation of the formatting of these mitigation scenario outputs.

Interactions

DKK Pacific-wide	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.819	0.939	0.782	0.950	0.732
fsh	0.922	0.741	0.861	0.704	0.872	0.653
CL	0.820	0.640	0.759	0.603	0.771	0.552
A	0.937	0.757	0.876	0.719	0.887	0.669
B	0.879	0.698	0.818	0.661	0.829	0.610
fsh A	0.871	0.691	0.810	0.653	0.822	0.603
fsh B	0.825	0.644	0.764	0.607	0.775	0.556
CL A	0.783	0.603	0.722	0.565	0.734	0.515
CL B	0.749	0.568	0.688	0.531	0.699	0.480
CL fsh	0.776	0.595	0.715	0.558	0.726	0.507
CL fsh A	0.745	0.565	0.684	0.527	0.696	0.477
CL fsh B	0.718	0.537	0.657	0.500	0.668	0.449

At-vessel mortalities

DKK Pacific-wide	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.990	0.994	0.985	0.999	0.984
fsh	0.846	0.836	0.840	0.832	0.845	0.831
CL	0.615	0.605	0.609	0.601	0.614	0.600
A	0.862	0.851	0.855	0.847	0.861	0.846
B	0.737	0.726	0.730	0.722	0.736	0.721
fsh A	0.733	0.723	0.727	0.719	0.732	0.718
fsh B	0.630	0.619	0.624	0.615	0.629	0.614
CL A	0.532	0.522	0.526	0.517	0.531	0.516
CL B	0.456	0.445	0.449	0.441	0.455	0.440
CL fsh	0.523	0.512	0.516	0.508	0.522	0.507
CL fsh A	0.453	0.442	0.447	0.438	0.452	0.437
CL fsh B	0.389	0.379	0.383	0.374	0.388	0.373

Figure L2. Simulation testing results for leatherback sea turtles (*Dermochelys coriacea*) for the Pacific Ocean. Interactions are shown in the upper panel; at-vessel mortalities are shown in the lower panel. Cell values and colours indicates the strength of reduction relative to the status quo (SQ) shown in the upper left corner as 1.00: red = no change; green = maximum reduction. Rows and columns specify mitigation options for deep and shallow set longlines, respectively. The table of mitigation scenarios and associated text in Section 4.5.3 provides a full explanation of the formatting of these mitigation scenario outputs.

Interactions

TTL Pacific-wide	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.804	0.948	0.768	0.951	0.718
fsh	0.941	0.745	0.889	0.709	0.892	0.659
CL	0.847	0.651	0.795	0.615	0.798	0.565
A	0.908	0.712	0.855	0.676	0.859	0.626
B	0.849	0.653	0.796	0.617	0.800	0.567
fsh A	0.865	0.669	0.813	0.633	0.816	0.583
fsh B	0.816	0.620	0.764	0.584	0.767	0.535
CL A	0.792	0.596	0.740	0.560	0.743	0.510
CL B	0.757	0.561	0.704	0.525	0.708	0.475
CL fsh	0.812	0.616	0.760	0.580	0.763	0.530
CL fsh A	0.766	0.570	0.714	0.534	0.717	0.485
CL fsh B	0.737	0.541	0.685	0.505	0.688	0.456

At-vessel mortalities

TTL Pacific-wide	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.976	0.986	0.967	0.998	0.965
fsh	0.883	0.859	0.869	0.850	0.881	0.848
CL	0.631	0.606	0.617	0.597	0.629	0.595
A	0.776	0.752	0.763	0.743	0.775	0.741
B	0.635	0.611	0.621	0.602	0.633	0.600
fsh A	0.691	0.667	0.677	0.658	0.689	0.656
fsh B	0.569	0.545	0.556	0.536	0.568	0.534
CL A	0.497	0.472	0.483	0.463	0.495	0.461
CL B	0.409	0.385	0.396	0.376	0.408	0.374
CL fsh	0.559	0.535	0.545	0.526	0.557	0.524
CL fsh A	0.442	0.418	0.428	0.409	0.440	0.407
CL fsh B	0.367	0.343	0.354	0.334	0.366	0.332

Figure L3. Simulation testing results for loggerhead sea turtles (*Caretta caretta*) for the Pacific Ocean. Interactions are shown in the upper panel; at-vessel mortalities are shown in the lower panel. Cell values and colours indicates the strength of reduction relative to the status quo (SQ) shown in the upper left corner as 1.00: red = no change; green = maximum reduction. Rows and columns specify mitigation options for deep and shallow set longlines, respectively. The table of mitigation scenarios and associated text in Section 4.5.3 provides a full explanation of the formatting of these mitigation scenario outputs.

Interactions

LKV Pacific-wide	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.890	0.965	0.866	0.929	0.796
fsh	0.908	0.798	0.874	0.775	0.838	0.704
CL	0.780	0.669	0.745	0.646	0.709	0.575
A	0.898	0.787	0.863	0.764	0.827	0.693
B	0.809	0.699	0.774	0.675	0.738	0.605
fsh A	0.823	0.713	0.788	0.689	0.752	0.619
fsh B	0.750	0.639	0.715	0.616	0.679	0.546
CL A	0.716	0.606	0.681	0.582	0.646	0.512
CL B	0.662	0.551	0.627	0.528	0.591	0.458
CL fsh	0.723	0.612	0.688	0.589	0.652	0.518
CL fsh A	0.670	0.560	0.635	0.536	0.599	0.466
CL fsh B	0.625	0.515	0.590	0.491	0.554	0.421

At-vessel mortalities

LKV Pacific-wide	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.981	0.989	0.973	0.997	0.970
fsh	0.854	0.835	0.843	0.827	0.851	0.824
CL	0.637	0.618	0.626	0.611	0.634	0.608
A	0.831	0.812	0.820	0.805	0.828	0.801
B	0.686	0.666	0.675	0.659	0.682	0.656
fsh A	0.712	0.693	0.701	0.685	0.709	0.682
fsh B	0.590	0.571	0.580	0.564	0.587	0.561
CL A	0.533	0.514	0.523	0.507	0.530	0.504
CL B	0.444	0.424	0.433	0.417	0.440	0.414
CL fsh	0.546	0.526	0.535	0.519	0.543	0.516
CL fsh A	0.458	0.439	0.448	0.432	0.455	0.429
CL fsh B	0.384	0.364	0.373	0.357	0.380	0.354

Figure L4. Simulation testing results for olive ridley sea turtles (*Lepidochelys olivacea*) for the Pacific Ocean. Interactions are shown in the upper panel; at-vessel mortalities are shown in the lower panel. Cell values and colours indicates the strength of reduction relative to the status quo (SQ) shown in the upper left corner as 1.00: red = no change; green = maximum reduction. Rows and columns specify mitigation options for deep and shallow set longlines, respectively. The table of mitigation scenarios and associated text in Section 4.5.3 provides a full explanation of the formatting of these mitigation scenario outputs.

Interactions

TUG Pacific-wide	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.855	0.944	0.820	0.915	0.734
fsh	0.906	0.760	0.850	0.725	0.820	0.640
CL	0.808	0.663	0.752	0.628	0.723	0.542
A	0.910	0.764	0.854	0.730	0.825	0.644
B	0.833	0.687	0.777	0.652	0.747	0.567
fsh A	0.835	0.690	0.779	0.655	0.750	0.569
fsh B	0.774	0.629	0.718	0.594	0.689	0.508
CL A	0.754	0.609	0.698	0.574	0.669	0.488
CL B	0.708	0.562	0.652	0.528	0.623	0.442
CL fsh	0.754	0.609	0.698	0.574	0.669	0.488
CL fsh A	0.711	0.566	0.655	0.531	0.626	0.445
CL fsh B	0.674	0.529	0.618	0.494	0.589	0.408

At-vessel mortalities

TUG Pacific-wide	SWO=SQ OTH=SQ	SWO=SQ OTH=CL	SWO=SQ OTH=fsh	SWO=SQ OTH=CL fsh	SWO=CL fsh OTH=SQ	SWO=CL fsh OTH=CL fsh
SQ	1.000	0.964	0.977	0.950	0.994	0.944
fsh	0.859	0.823	0.837	0.810	0.853	0.803
CL	0.650	0.613	0.627	0.600	0.643	0.594
A	0.834	0.798	0.811	0.784	0.828	0.778
B	0.692	0.656	0.669	0.642	0.686	0.636
fsh A	0.721	0.685	0.698	0.671	0.715	0.665
fsh B	0.602	0.566	0.579	0.552	0.596	0.546
CL A	0.548	0.512	0.525	0.499	0.542	0.492
CL B	0.461	0.425	0.439	0.412	0.455	0.406
CL fsh	0.564	0.527	0.541	0.514	0.557	0.508
CL fsh A	0.479	0.443	0.457	0.430	0.473	0.423
CL fsh B	0.407	0.370	0.384	0.357	0.401	0.351

Figure L5. Simulation testing results for green sea turtles (*Chelonia mydas*) for the Pacific Ocean. Interactions are shown in the upper panel; at-vessel mortalities are shown in the lower panel. Cell values and colours indicates the strength of reduction relative to the status quo (SQ) shown in the upper left corner as 1.00: red = no change; green = maximum reduction. Rows and columns specify mitigation options for deep and shallow set longlines, respectively. The table of mitigation scenarios and associated text in Section 4.5.3 provides a full explanation of the formatting of these mitigation scenario outputs.

Annex M. Dragonfly report on Delphi survey for Pacific sea turtle relative abundances

Delphi survey to assess the spatial distribution of sea turtles in the Pacific Ocean

Report to the Pacific Community (SPC)

Authors:
Philipp Neubauer
Katrin Berkenbusch
Chris Knox
Edward Abraham

DRAGONFLY
Data Science

PO Box 27535, Wellington 6141
New Zealand
dragonfly.co.nz

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1. INTRODUCTION

Fisheries worldwide interact with a range of non-target species, resulting in the incidental capture of marine mammals, seabirds, and marine turtles (e.g., Lascelles et al. 2014, Lewison et al. 2014). For a number of megafaunal species, this fisheries bycatch is a significant source of mortality, leading to population declines and threatening the viability of populations. For sea turtles, incidental captures in fisheries have been identified as a primary threat to their populations in different regions, including the Atlantic and Pacific oceans (Wallace et al. 2011, Clarke et al. 2014).

In the Pacific Ocean, four sea turtles species are considered vulnerable to fisheries interactions, including green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), and olive ridley (*Lepidochelys olivacea*). Each of these species is ranked as either endangered or vulnerable by the International Union for Conservation of Nature, and the reduction of bycatch mortalities has been highlighted as a priority for their conservation.

The incidental capture of sea turtles in tuna longline fisheries has led to concerted efforts to reduce and mitigate their bycatch. These efforts include a set of workshops under the Areas Beyond National Jurisdiction (ABNJ, or Common Oceans) Tuna Project (see Western and Central Pacific Fisheries Commission 2016). The first workshop was held in February 2016, and focused on characterising the current interactions and mortality rates of sea turtles in pelagic longline fisheries in the Pacific Ocean. The investigation into the effectiveness of sea turtle mitigation measures included the use of simulation models to determine the overlap between sea turtles and longline fisheries. These models require information of the spatial distribution of sea turtles, and although some of this spatial information is currently available, these data are considered to be incomplete.

The simulation models developed in the first workshop used basic relative abundance surfaces of the four sea turtle species, based on maps of regional management units used by the State of the World's Sea Turtles (SWOT) project. It was acknowledged at the workshop that the maps represent the best information available, but contain a number of uncertainties, and also need revision in some key areas. For this reason, it was recommended that the spatial information be updated and review by experts in the future. The current project followed this recommendation by conducting an Internet-based Delphi survey of expert knowledge of the spatial distribution of green, leatherback, loggerhead and olive ridley sea turtles in the Pacific Ocean, based on SWOT data. The survey was aimed at augmenting existing information by soliciting expert knowledge.

The Delphi technique is a research method for data-poor situations, as it provides a structured approach for obtaining expert opinion in a systematic and transparent way (Linstone & Turoff 2002, MacMillan & Marshall 2006, Cole et al. 2013). The Delphi process allows experts to contribute their information independently, and experts are able to participate in the survey remotely. This technique involves an iterative process based on existing information, facilitating contributions by participating experts, and includes a feedback approach to build consensus, including a measure of uncertainty. Through this technique, it is possible to capture information that is otherwise not available.

This report presents the findings from the Delphi survey that was conducted to support subsequent workshops on sea turtle bycatch mitigation in pelagic longline fisheries in the Pacific Ocean.

2. METHODS

2.1 Practical implementation: the Delphi web application

The Delphi survey sought expert knowledge to obtain estimates of the relative abundance of the four sea turtle species included in the assessment, green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), and olive ridley (*Lepidochelys olivacea*). The survey was implemented as a web application, which allowed participants to use an e-mail link to log in and complete the survey. All contributions remained anonymous, participants were not expected to share confidential data.

The survey consisted of two rounds. In the first round, participants were asked to independently estimate the relative abundance of each sea turtle species. In the second round, a summary of the previous results was provided to the participants, who were invited to confirm or update their responses in view of the other participants' answers.

The web application consisted of a map for each sea turtle species, showing a prior distribution of the species across the Pacific Ocean (Figure 1), based on expert-drawn maps from SWOT data during the "Workshop on joint analysis of sea turtles mitigation effectiveness". The relative abundance of each species was standardised across the four sea turtle species, so that abundances were on the same relative scale. To provide spatial guidance, respondents had the option to add Exclusive Economic Zone (EEZ) and Western Central and Pacific Fisheries (WCPF) convention area boundaries to the sea turtle base maps.

Each map contained a raster grid representing 5° by 5° cells, resulting in 545 squares (cells) across the Pacific Ocean. Respondents were asked to categorise each cell into one of five categories:

- Absence (<1% of maximum density),
- Low density (1–33% of maximum density),
- Medium density (34–66% of maximum density),
- High density (67–99% of maximum density),
- Maximum density.

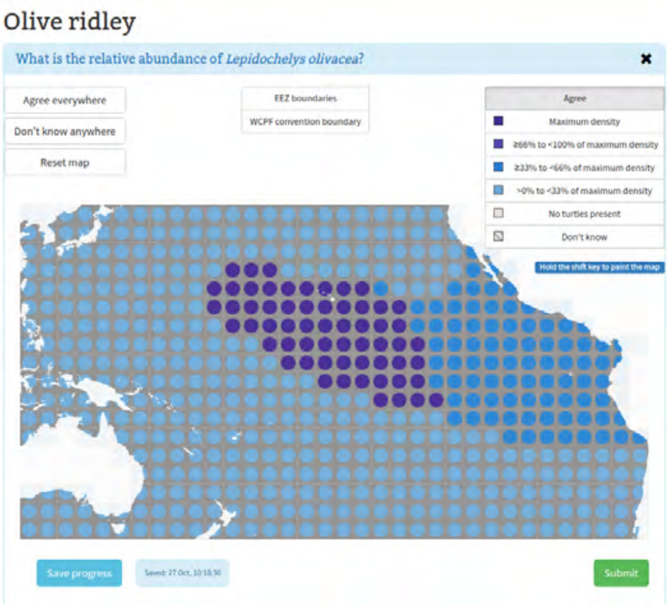

Figure 1: Partial screenshot of the initial web-app display for the first round of the Delphi survey of the relative abundance of sea turtles in the Pacific Ocean. Circles indicate the category from the prior distribution. Buttons in the top right corner allowed participants to choose the category to use with the colouring tool, including the option to agree with the prior map.

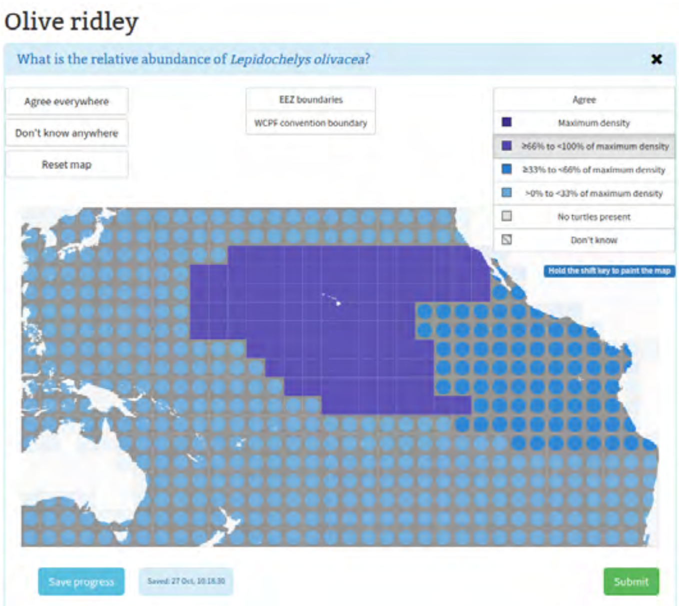

Figure 2: Partial screenshot of a participant using the web-app during the first round of the Delphi survey of the relative abundance of sea turtles in the Pacific Ocean. Colouring is arbitrary for illustrative purposes, with the participant providing information. Circles indicate the category from the prior distribution, while filled squares indicate the respondent's categorisation. Buttons in the top right corner allowed participants to choose the category to use with the colouring tool, including the option agree with the prior map.

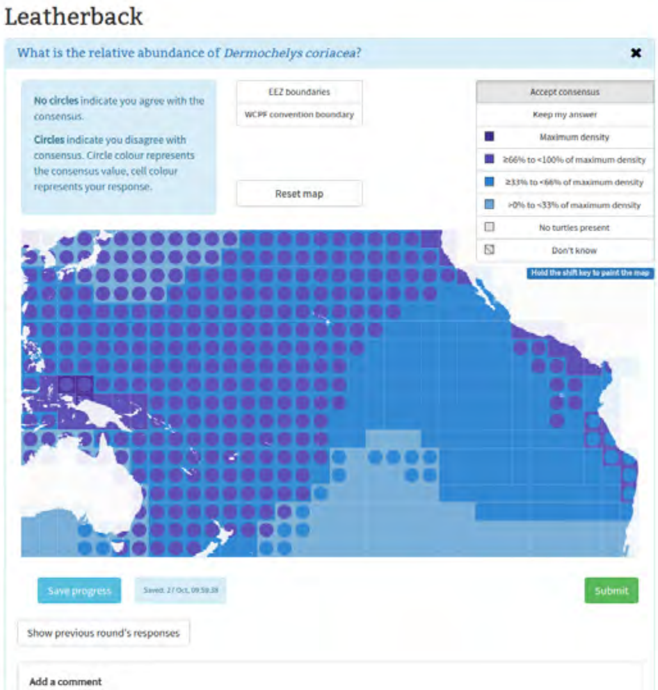

Figure 3: Partial screenshot of the web-app display for the second round of Delphi survey of the relative abundance of sea turtles in the Pacific Ocean. The image shows the display for a randomly chosen participant. Buttons in the top right corner allowed participants to choose the category to use with the colouring tool, including the option to keep previous answers.

A colouring tool was implemented to allow respondents to colour parts of the map according to the categories listed above (Figure 2). Additional options allowed respondents to agree with the prior distribution, to leave parts of the map blank or to reset the map to the prior distribution. All submitted responses were saved in a database for analysis, and imported to R for modelling.

The display on the website was round-specific. The first round was the initial stage in which respondents answered independently of each other, with only the prior map for guidance. For the second round, the display of the prior distribution was replaced by the consensus map (see 2.2 below), and each participant's answers were overlaid to highlight where their answers differed from the consensus map (Figure 3). Participants also had the option to access the responses from the other participants, which were displayed anonymously as individual maps below their own response. Participants were then able to alter their answers or to retain them.

2.2 Consensus maps: Modelling respondents' data

The following model description uses the generic term "turtle" as the model was identical for all species. A consensus map for each species was derived from respondents' answers within a Bayesian modelling framework. This framework allowed accounting for incomplete answers, and the possibility that respondents who submitted partial maps may have had different perceptions about the maximum density for any species. Furthermore, the approach allowed us to explicitly model the un-evenness of the categories in terms of actual underlying relative abundance. Lastly, the model-based approach allowed for a model-based smoothing of the consensus map, which avoids a patchy consensus distribution map.

The consensus model for each turtle species had two layers: the first layer modelled the categorical answer $y_{i,s}$ by respondent i for cell s as a draw from a categorical distribution (i.e., a multinomial with a single draw). Thus

$$y_{i,s} \sim \text{Cat}(\mathbf{p_{i,s}}). \tag{1}$$

The categorical response depends on probabilities $\mathbf{p_{i,s}} = p_{i,s,1}, ..., p_{i,s,5}$, with $p_{i,s,k}$ the probability that participant i answers category k for cell s. These probabilities were determined by the latent, continuous density of turtles (i.e., the second layer of the model). Thus, $p_{i,s,k} = P(Y_{i,s} = k)$, which we modelled using a beta density evaluated at the mid-point of category k, given beta parameters α_s and β_s. The latter are determined by the underlying turtle density in cell s. Thus

$$P(Y_{i,s} = k \mid \alpha_s, \beta_s) = \text{Beta}(\lambda_i x_k \mid \alpha_s, \beta_s), \tag{2}$$

where x_k is the mid-point of the category and λ_i is a "shift" parameter for respondents that did not provide an answer for all cells on the map. This parameter scales the categories of incomplete response relative to those of all other responses. The beta distribution was modelled using the mode α_s and concentration parameter β_s. This approach is more convenient for the beta distribution than a formulation for the mean and variance, which have to follow reciprocal constraints. The mode of the beta distribution represents the continuous underlying turtle density, which varies between zero (turtles absent, category 1) to 1 (maximum density, category 5). The concentration parameter models the level of agreement about the location of the mode (i.e., about the true density, and the density category; see Figure 4 for an illustration). Both parameters were modelled using a conditional auto-regressive spatial model on the lattice covering the map.

For the latent spatial model, the beta mode α_s at location s was logit-transformed (giving α'_s), whereas the concentration parameter was log-transformed (giving β'_s). We then applied the auto-regressive model as:

$$\alpha'_s \mid \alpha'_q, q \neq s \sim \text{Normal}(\rho \sum_{q=1}^{545} A_{ij} \alpha'_q, \tau_\alpha^{-1}), \tag{3}$$

$$\beta'_s \mid \beta'_q, q \neq s \sim \text{Normal}(\rho \sum_{q=1}^{545} A_{ij} \beta'_q, \tau_\beta^{-1}), \tag{4}$$

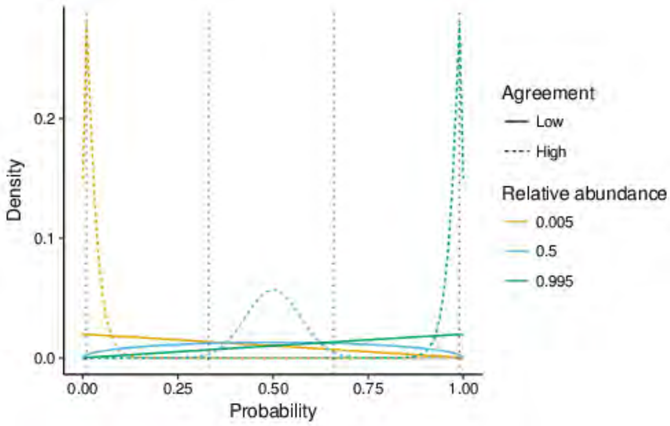

Figure 4: Example of the beta-distribution model used to derive the probabilities for each relative abundance category. Three relative abundance categories are illustrated here, with the mode centred at the mid-point of the category and two levels of agreement. At high agreement (large β), the probabilities are concentrated at the category mid-point, whereas with low agreement, probability densities are spread more evenly over the [0,1] interval.

where ρ is a common auto-regressive parameter, A is an adjacency matrix, and τ is a precision parameter. All priors were vaguely informative relative to the true scale of the parameters. The prior for λ_i was beta distributed with shape parameters $a_\lambda = 2$ and $b_\lambda = 1$, introducing a prior that is slightly in favour of equally aligned categories. Similarly, the prior for the spatial auto-correlation was chosen to give more weight to a map with auto-correlated cells by setting $a_\rho = 4$ and $b_\rho = 1$. Both τ_α and τ_β were given half-Cauchy priors with scale parameter $c_\tau = 5$.

The model was implemented in Stan (Carpenter et al. 2015), a Bayesian modelling language that implements efficient No-U-Turn Markov Chain Monte Carlo (MCMC) sampling based on automatic differentiation. The MCMC was run with two chains per species for 2500 iterations. 500 iterations per chain were discarded as burn-in, and as nearly no auto-correlation was evident, every fourth sample of the MCMC was kept for further analysis, leaving 1000 samples per species in total between the two chains. Convergence was assessed visually and using Gelman-Rubin diagnostics as calculated by rStan, the R interface to the Stan library (see Appendix A for the full model code, and Appendix B for a simulated example).

3. RESULTS

3.1 Delphi survey participation

Participation in the survey varied between rounds and also across the four sea turtle species (Table 1). In the first round, there were 9 to 13 participants, depending on the species. Fewer participants responded in the second round, ranging from 7 participants for *Caretta caretta* and 8 participants for *Chelonia mydas* (see Appendices C and D for individual responses in the first and second rounds).

Table 1: Number of participants in the Delphi survey of the spatial distribution of sea turtles in the Pacific Ocean. Total indicates the number of unique participants for each species.

Round	*Caretta caretta*	*Chelonia mydas*	*Dermochelys coriacea*	*Lepidochelys olivacea*
1	11	13	12	9
2	7	8	7	7
Total	12	14	12	11

3.2 Delphi survey responses—Round 1

Information from the participants in the first round of the survey was used to generate the modal map of sea turtle abundances (Figure 5). The consensus model converged quickly and provided qualitatively sensible answers, both on the continuous scale of the underlying estimated turtle densities (Figure 6) and density categories. Due to a lack of complete agreement, the categories on the consensus maps were condensed towards categories for low to high densities. This effect can be reversed by re-scaling the estimated density field to a maximum of one, thus assuring that the estimated distribution falls within the maximum category in at least some cells (Figure 7). The level of agreement was quantified spatially using the estimates of β_s (Figure 8).

3.3 Delphi survey responses—Round 2

Although fewer people updated their answers in round two, these updates led to a smoother modal map, suggesting increased agreement (Figure 9). The posterior distribution for the agreement measure, β_s was higher overall on the maps (Figure 10). Although the continuous response was generally similar between rounds (Figures 6, 11), the categorical map for round two was more nuanced, with smaller areas of maximum abundance (Figure 12).

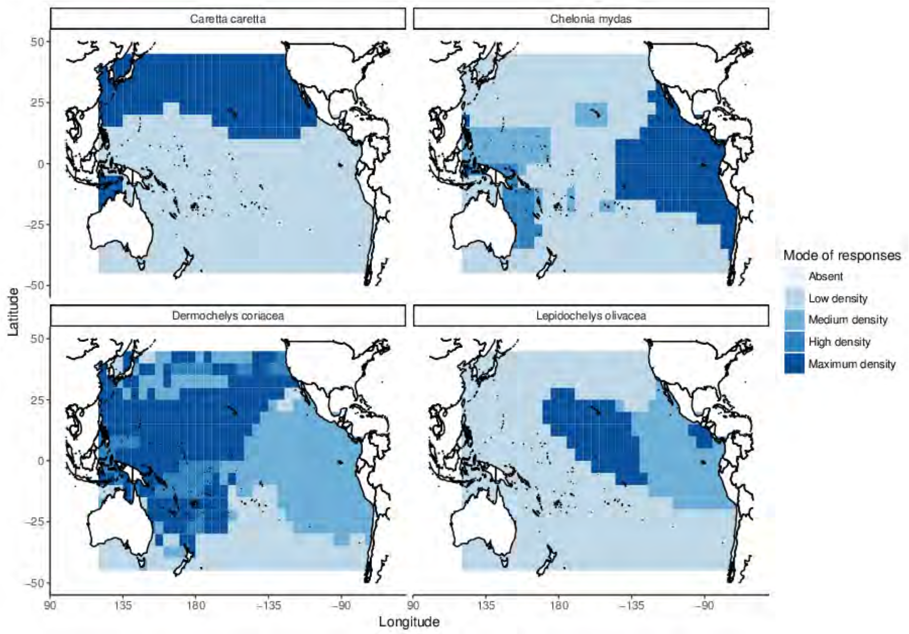

Figure 5: Modal response (i.e., the most frequent response) across all respondents in the first round of the Delphi survey. Colour shading indicates the relative abundance of each of the four sea turtle species in the Pacific Ocean, based on categories used in the survey.

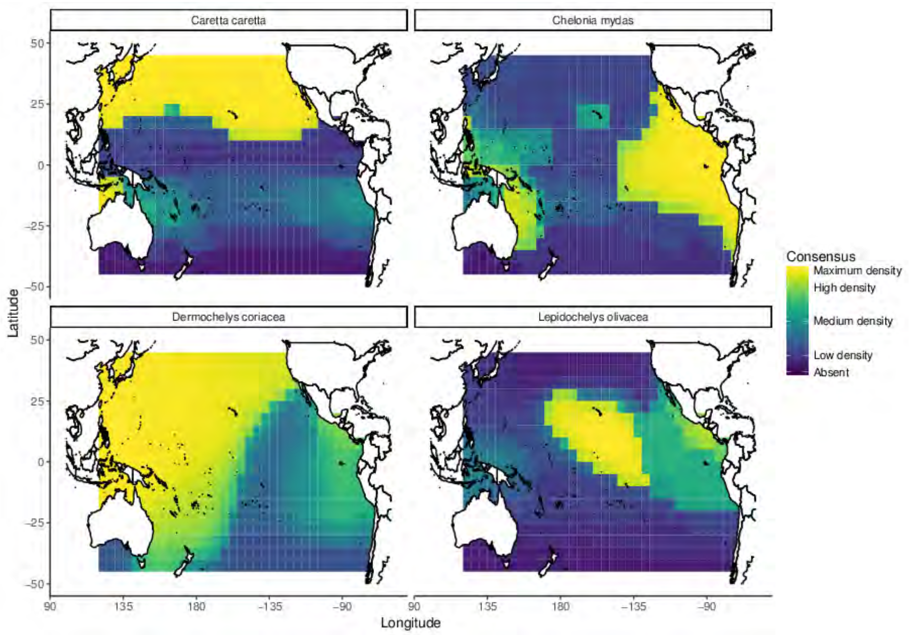

Figure 6: Estimate of the latent continuous density of sea turtles in the consensus model run for responses in the first round of the Delphi survey. Colour shading indicates the relative abundance of each of the four sea turtle species in the Pacific Ocean, based on categories used in the survey.

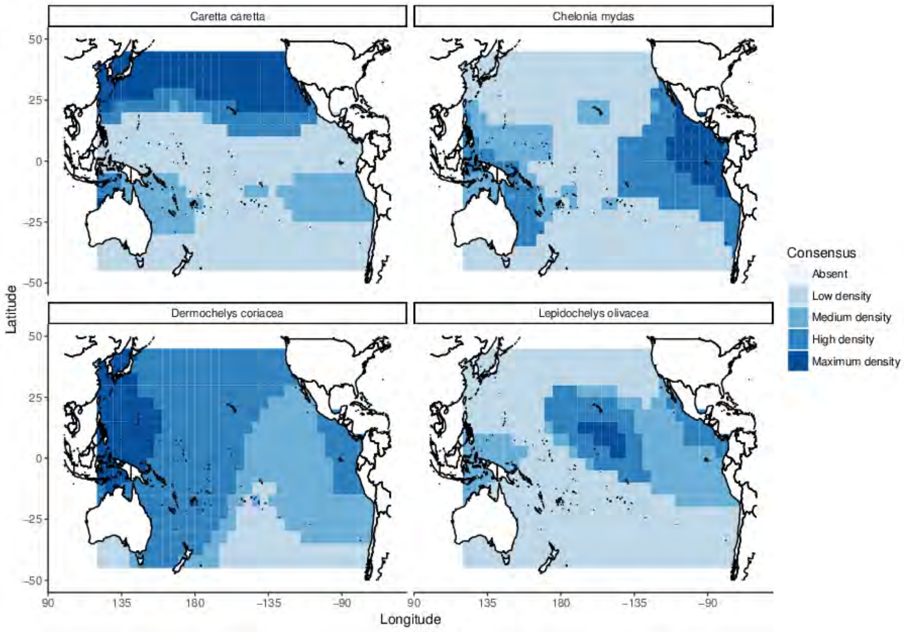

Figure 7: Consensus map from the first round of the Delphi survey. The map was produced by scaling the latent continuous density to a maximum of one and converting the estimated density of sea turtles in the consensus model to a categorical distribution, based on categories used in the survey.

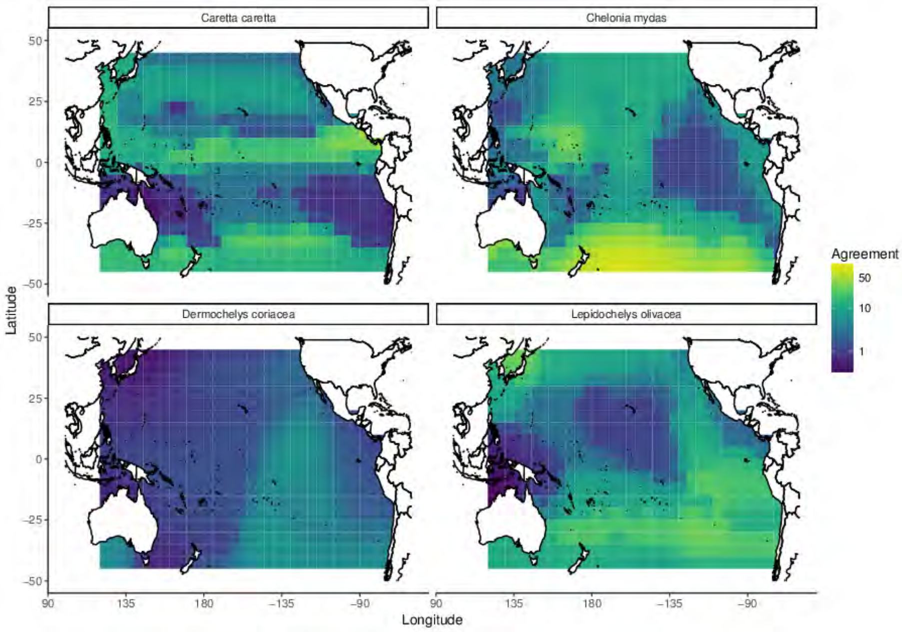

Figure 8: Beta weight parameter (on $\log_{10}$ scale), quantifying the level of consensus on the map for answers from the first round of the Delphi survey.

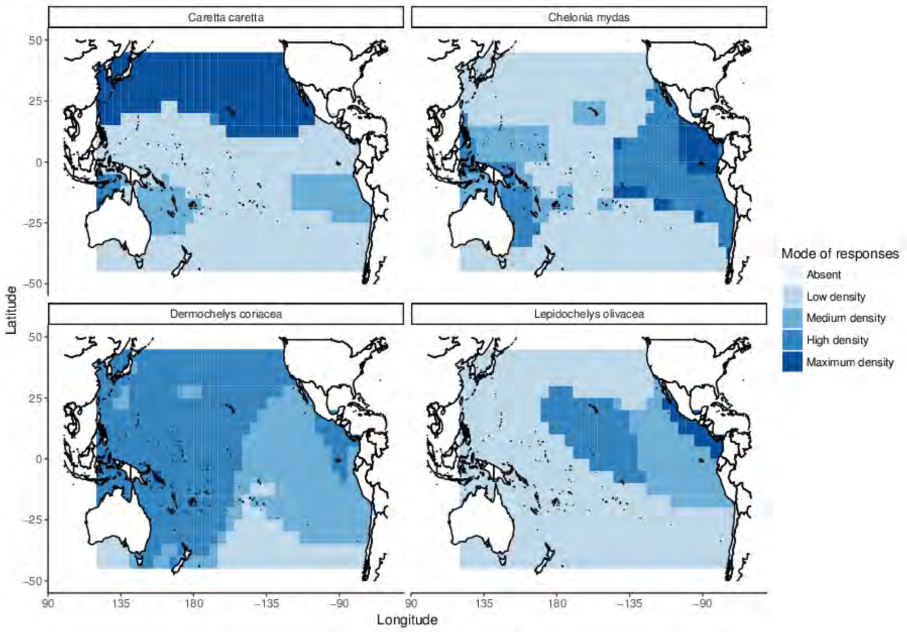

Figure 9: Modal response (i.e., the most frequent response) across all respondents in the second round of the Delphi survey. Colour shading indicates the relative abundance of each of the four sea turtle species in the Pacific Ocean, based on categories used in the survey.

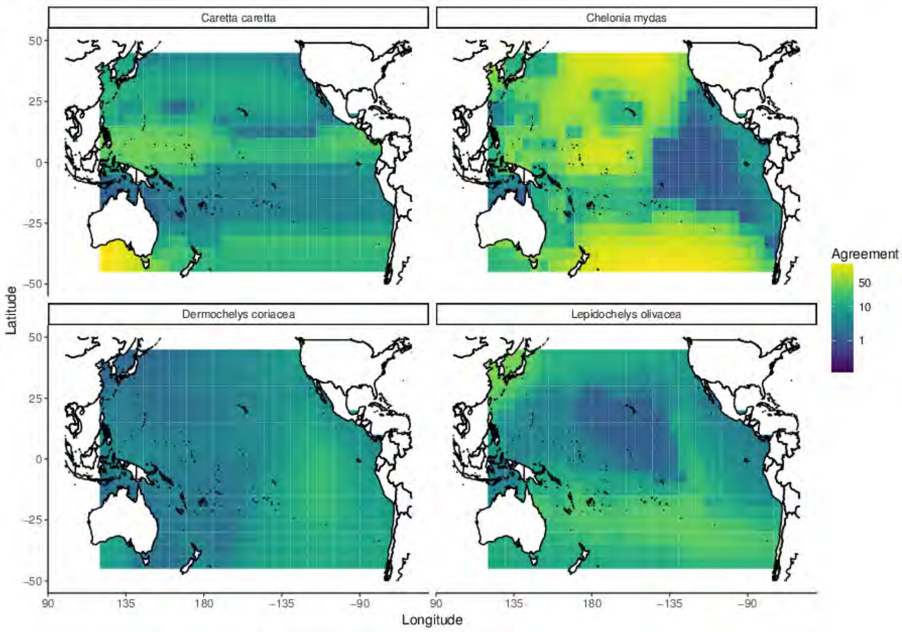

Figure 10: Beta weight parameter (on $\log_{10}$ scale), quantifying the level of consensus on the map for answers from the second round of the Delphi survey.

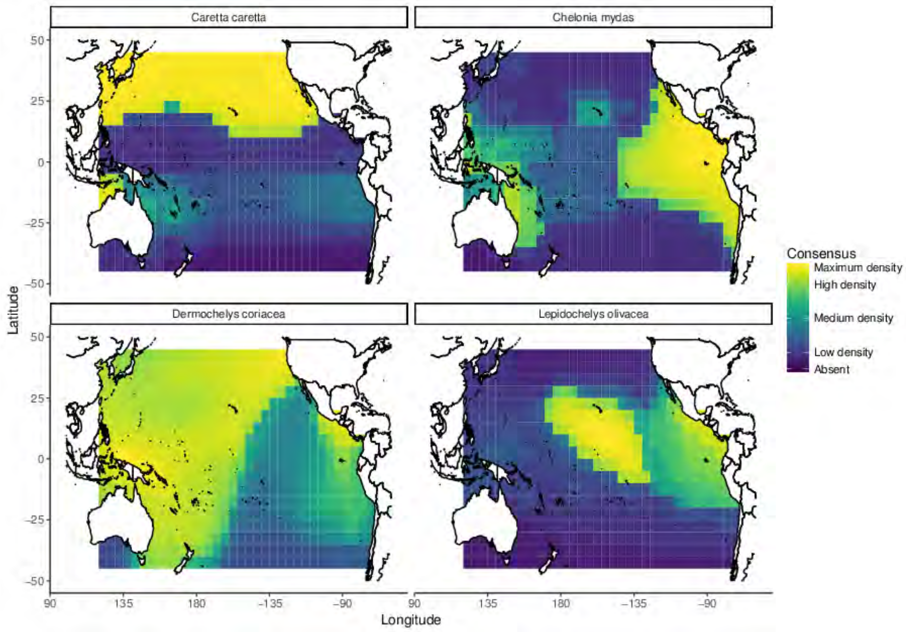

Figure 11: Estimate of the latent continuous density of sea turtles in the consensus model run for responses in the second round of the Delphi survey.

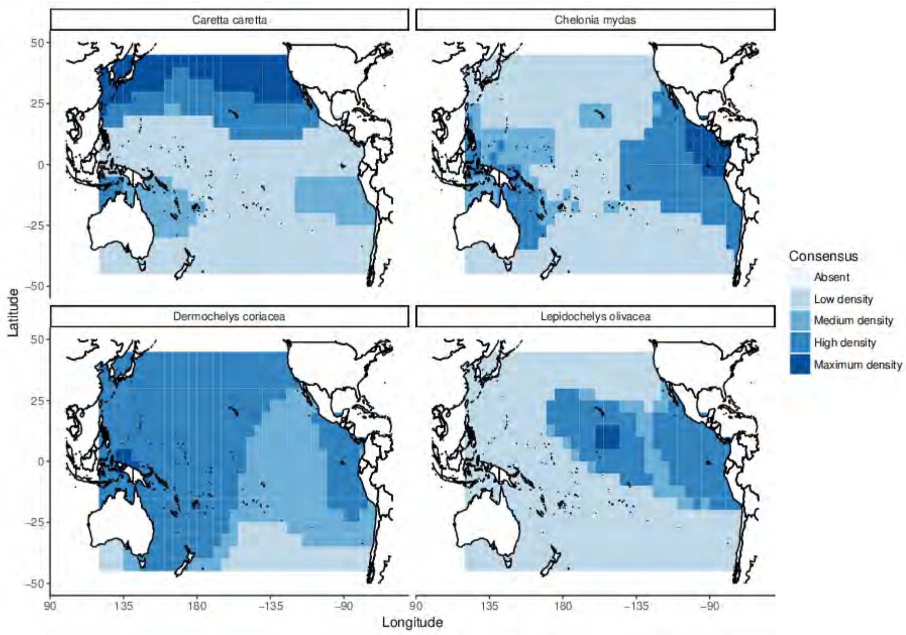

Figure 12: Consensus map from the second round of the Delphi survey. The map was produced by scaling the latent continuous density to a maximum of one and converting the estimated density of sea turtles in the consensus model to a categorical distribution, based on categories used in the survey.

4. DISCUSSION

This project implemented a Delphi process in the form of an online application. The goal of the Delphi survey was to elucidate a consensus distribution of relative abundances for each of four species of sea turtles from expert knowledge. Although uptake was slow initially, ultimately, a minimum of 11 experts filled out distribution maps for each of the four turtle species. The round-based system allowed for feedback between rounds, and led to greater consensus during the second round of the survey.

The Bayesian consensus model allowed us to explicitly model the underlying relative abundance distribution with a smooth latent model, which in turn accomodated incomplete answers. The estimated relative abundance was associated with a spatially varying measure of agreement, which would allow for uncertainty to be carried forward into a risk assessment for sea turtles.

5. ACKNOWLEDGMENTS

We are grateful to the experts that participated in the Delphi survey and contributed their time and expertise. Many thanks to Shelley Clarke (WCPFC) and Neville Smith (Pacific Community) for co-ordinating the survey.

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APPENDIX A Consensus model code

Stan model code used to derive the consensus maps of the relative abundance of each of the four sea turtle species included in the Delphi survey. The survey sought expert knowledge to obtain estimates of the relative abundance of green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), and olive ridley (*Lepidochelys olivacea*) sea turtles in the Pacific Ocean.

```
data {
  int<lower = 1> nsamp;
  int<lower = 1> ngrid;
  int<lower = 1> nresp;
  int<lower = 1> ncat;
  int ts[nresp];
  real x[ncat+1];
  real y[ncat];
  int dist_samp[nsamp];
  int idx[nsamp];
  int resp_ix[nsamp];
  int W_n;                // number of adjacent region pairs
  int W1[W_n];            // first half of adjacency pairs
  int W2[W_n];            // second half of adjacency pairs
 vector[ngrid] D_sparse;    // diagonal of D (number of neigbors for each site)
 vector[ngrid] lambda;     // eigenvalues of invsqrtD * W * invsqrtD
}
parameters {

  vector[ngrid] phi;
  real<lower = 0> tau;
  #real<lower = 0> mu_phi;
  #real<lower = 0> mu_tau;
  vector[ngrid] tau_beta;
  real<lower = 0> tau2;
  real<lower = 0, upper = 1> alpha;
  real<lower = 0, upper = 1> est_y[nresp];
}
transformed parameters{
  vector[ngrid] itau;
  vector[ngrid] a;
  vector[ngrid] b;
  vector[ngrid] iphi;
  vector[ncat] p[ngrid,nresp];
  vector[ncat] ys[nresp];


  for(i in 1:ngrid){

     itau[i] = exp(tau_beta[i]);
```

```
      iphi[i] = inv_logit(phi[i]);

      a[i] = iphi[i]*itau[i]+1;
      b[i]=  (1-iphi[i])*itau[i]+1;

      for (s in 1:nresp){

       for(k in 1:ncat) {
            ys[s,k] = ts[s]==1 ? y[k] : y[k]*est_y[s];

            p[i,s,k] = exp(beta_lpdf(ys[s,k]|a[i],b[i]));
           }
           p[i,s,] = p[i,s,]/sum(p[i,s,]);
      }
   }
}
model {
   row_vector[ngrid] phit_D; // phi' * D
   row_vector[ngrid] phit_W; // phi' * W
   vector[ngrid] ldet_terms;
   row_vector[ngrid] taut_D; // phi' * D
   row_vector[ngrid] taut_W; // phi' * W
   vector[ngrid] ldet_terms_tau;

#  tau_beta ~ cauchy(0,50);

  for (s in 1:nsamp) dist_samp[s] ~ categorical(p[idx[s],resp_ix[s],]);

   phit_D = (phi .* D_sparse)';
   phit_W = rep_row_vector(0, ngrid);
   for (i in 1:W_n) {
     phit_W[W1[i]] = phit_W[W1[i]] + phi[W2[i]];
     phit_W[W2[i]] = phit_W[W2[i]] + phi[W1[i]];
   }

   // prior for phi
   for (i in 1:ngrid) ldet_terms[i] = log1m(alpha * lambda[i]);
   target += 0.5 * ngrid * log(tau)
   + 0.5 * sum(ldet_terms)
   - 0.5 * tau * (phit_D * phi - alpha * (phit_W * phi)) ;
   tau ~ cauchy(0,5);

   ### tau
   taut_D = (tau_beta .* D_sparse)';
   taut_W = rep_row_vector(0, ngrid);
   for (i in 1:W_n) {
     taut_W[W1[i]] = taut_W[W1[i]] + tau_beta[W2[i]];
     taut_W[W2[i]] = taut_W[W2[i]] + tau_beta[W1[i]];
   }
```

```
  // prior for phi
  for (i in 1:ngrid) ldet_terms_tau[i] = log1m(alpha * lambda[i]);
  target += 0.5 * ngrid * log(tau2)
  + 0.5 * sum(ldet_terms_tau)
  - 0.5 * tau2 * (taut_D * tau_beta  - alpha * (taut_W * tau_beta)) ;
  tau2 ~ cauchy(0,5);


  #mu_tau ~ normal(0,10);
  #mu_phi ~ normal(0,10);
  alpha ~ beta(4,1);
  est_y ~ beta(2,1);
}
```

APPENDIX B Simulated example

The current analysis included an assessment of the robustness of the model to incomplete answers and "shifted" baselines for different experts participating in the Delphi survey (i.e., different perceptions of maximum sea turtle densities). This testing of the model used a set of simulations on a small grid. The simulations used the model as a generating model, starting with a continuous, auto-correlated density map (Figure B-1). This map can then be transformed into a categorical map using the abundance categories used in the Delphi survey.

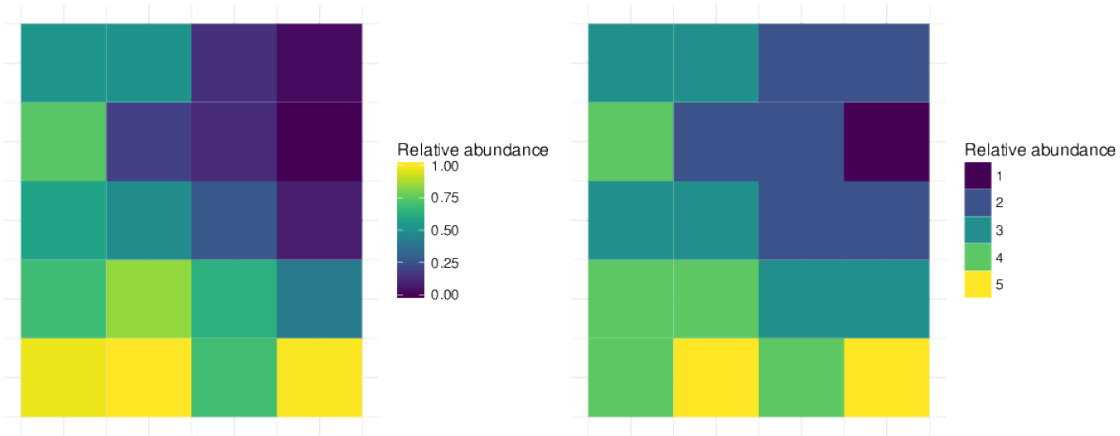

Figure B-1: Simulated continuous (left) and resulting categorical (right) relative abundance maps on a 5×4 lattice. Simulations were used to assess the model used for deriving consensus maps in the Delphi survey of sea turtle abundance in the Pacific Ocean.

Participants' answers were simulated with a value of $\beta = 10$ as the level of agreement. For a subset of four participants, parts of the answers were restricted to parts of the map only (Figure B-2), with relative abundance rescaled to the maximum abundance found on the incomplete maps (Figure B-3).

Simulations illustrate how the model estimated scaling factors for incomplete responses (Figure B-4), and used these scaling factors to determine the underlying relative density (Figure B-5).

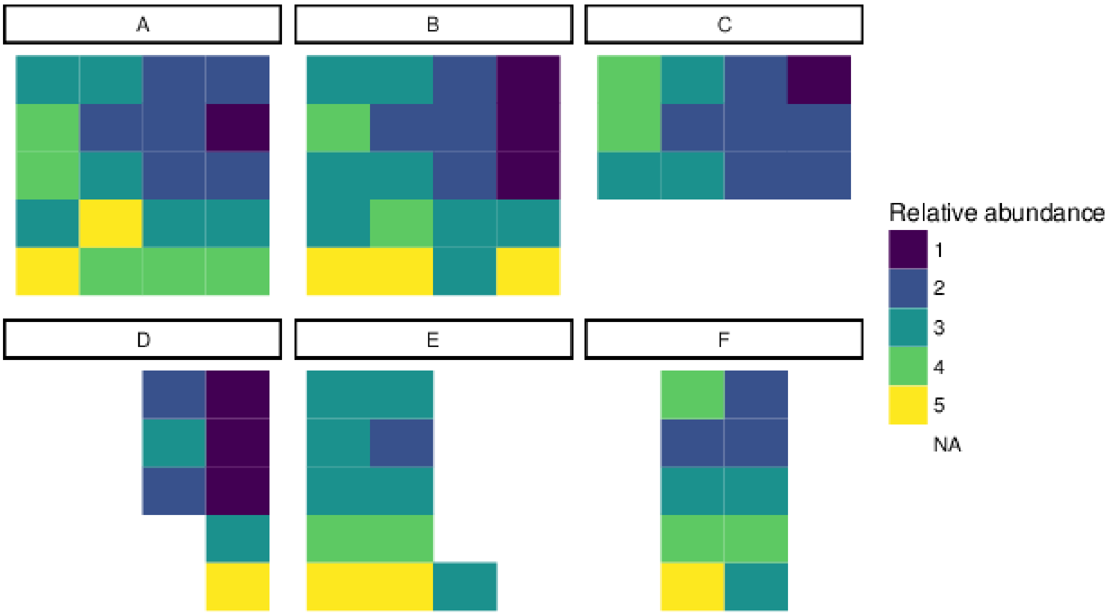

Figure B-2: Simulated answers for six of ten simulated participants, showing four incomplete answers. Simulations were used to assess the model used for deriving consensus maps in the Delphi survey of sea turtle abundance in the Pacific Ocean.

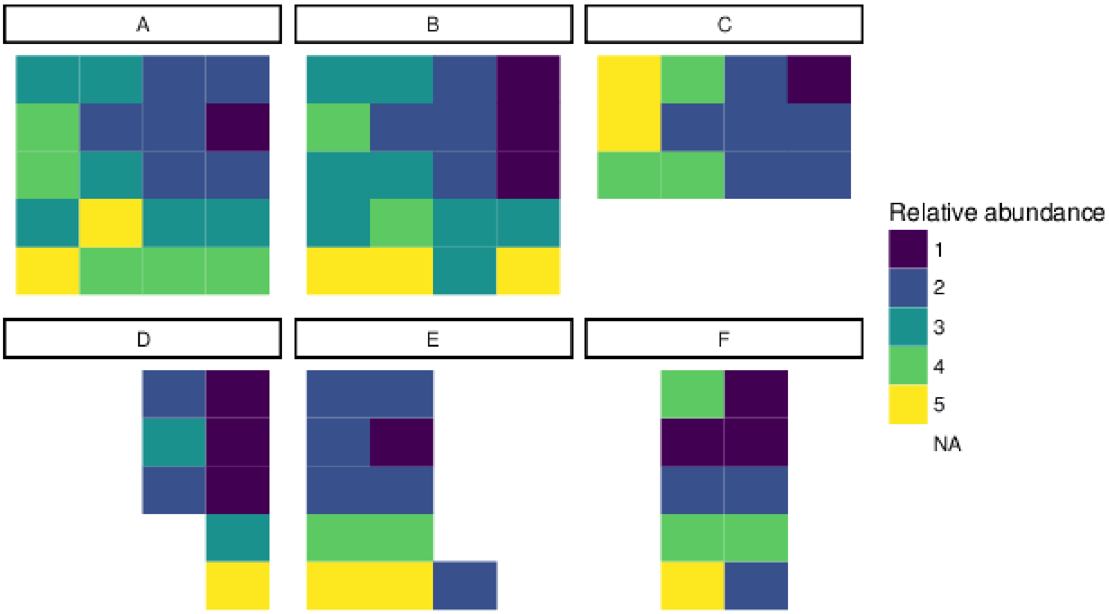

Figure B-3: Simulated answers for six of ten simulated participants, showing four incomplete answers, re-scaled to the maximum of the lattice for each participant. Simulations were used to assess the model used for deriving consensus maps in the Delphi survey of sea turtle abundance in the Pacific Ocean.

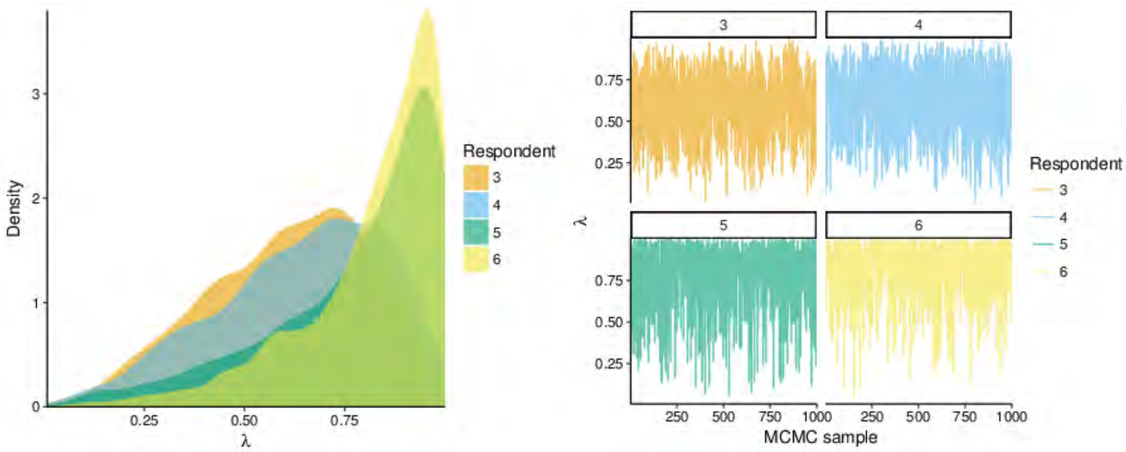

Figure B-4: Estimated scaling factors (λ) for incomplete answers in the Delphi survey, including Markov Chain Monte Carlo (MCMC) sampling. Scaling factors were estimated by the model for deriving consensus maps in the Delphi survey of sea turtle abundance in the Pacific Ocean.

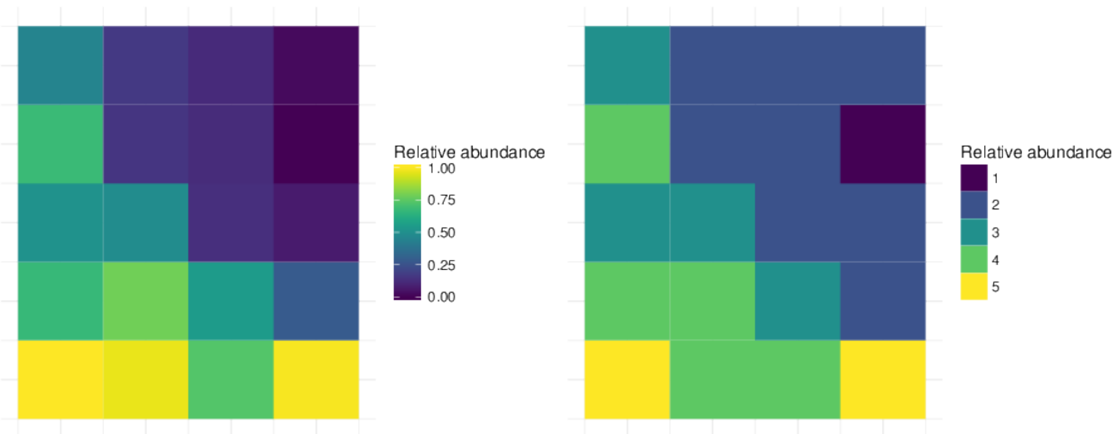

Figure B-5: Estimated continuous (left) and resulting categorical (right) relative abundance maps on a 5×4 lattice. Relative abundances were estimated using the model applied to derive consensus maps in the Delphi survey of sea turtle abundance in the Pacific Ocean.

APPENDIX C Respondent maps—Round 1

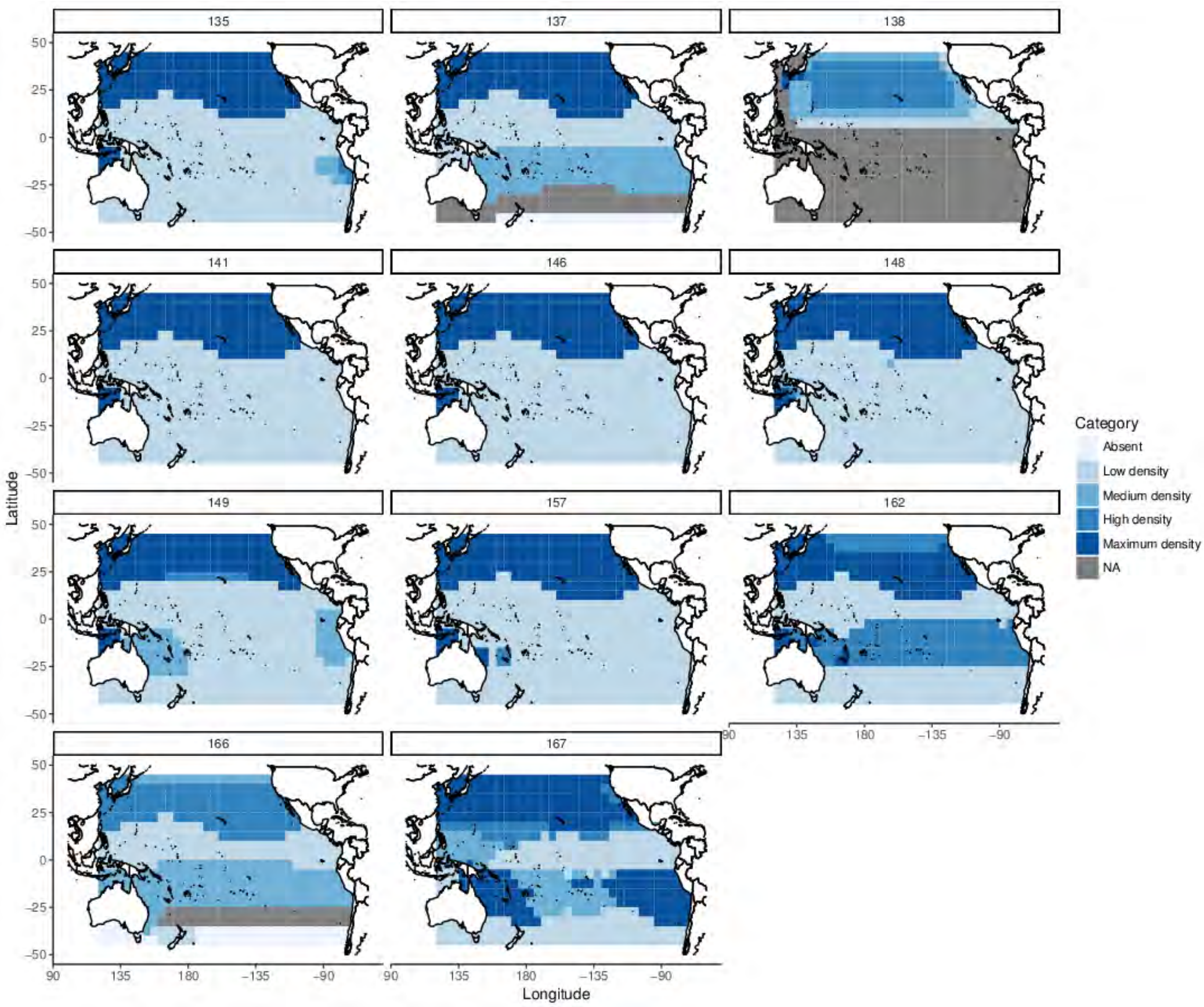

Figure C-6: Relative abundance maps for *Caretta caretta* from the individual participants in the first round of the Delphi survey. Colour shading indicates the abundance categories used in the survey.

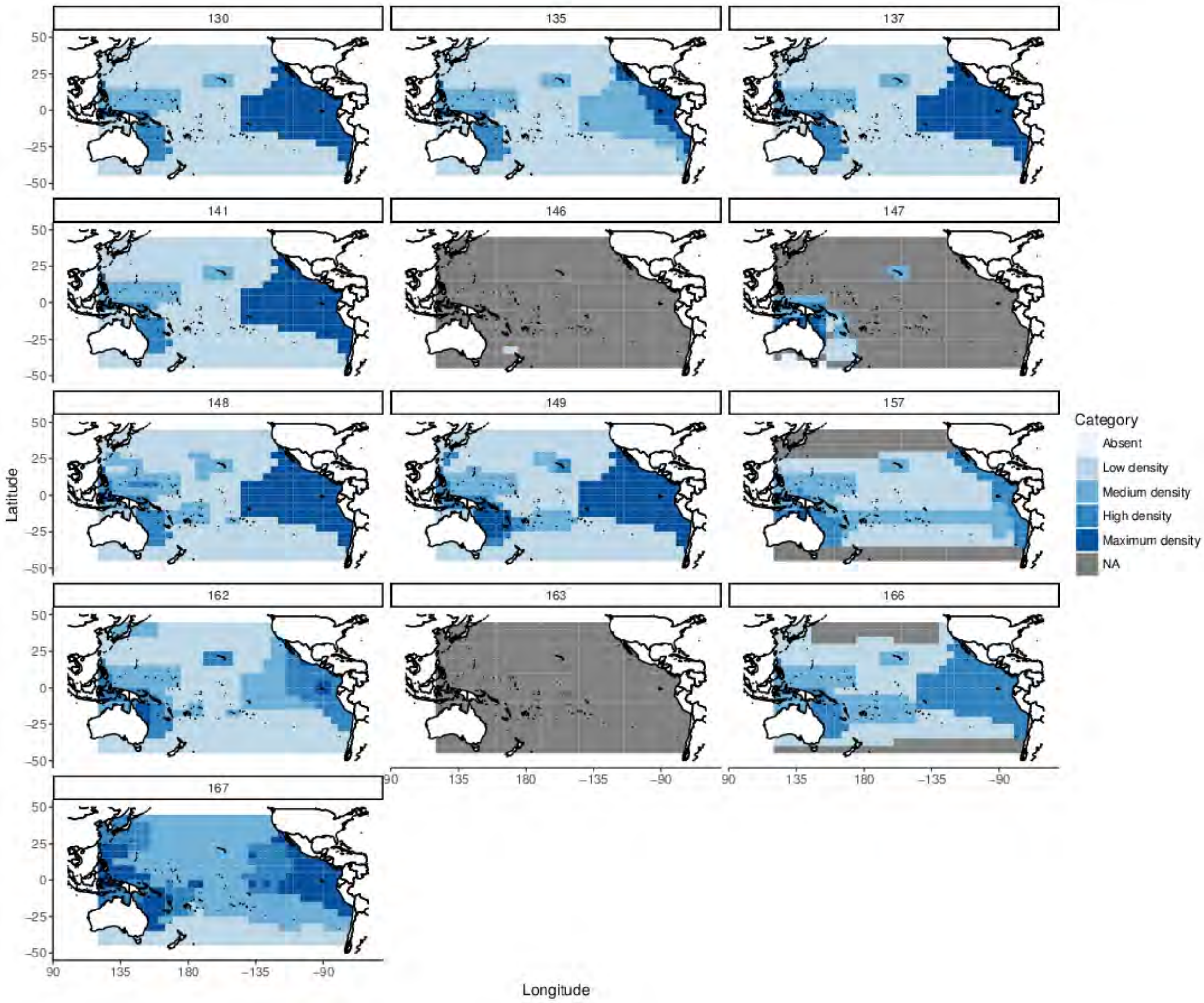

Figure C-7: Relative abundance maps for *Chelonia mydas* from the individual participants in the first round of the Delphi survey. Colour shading indicates the abundance categories used in the survey.

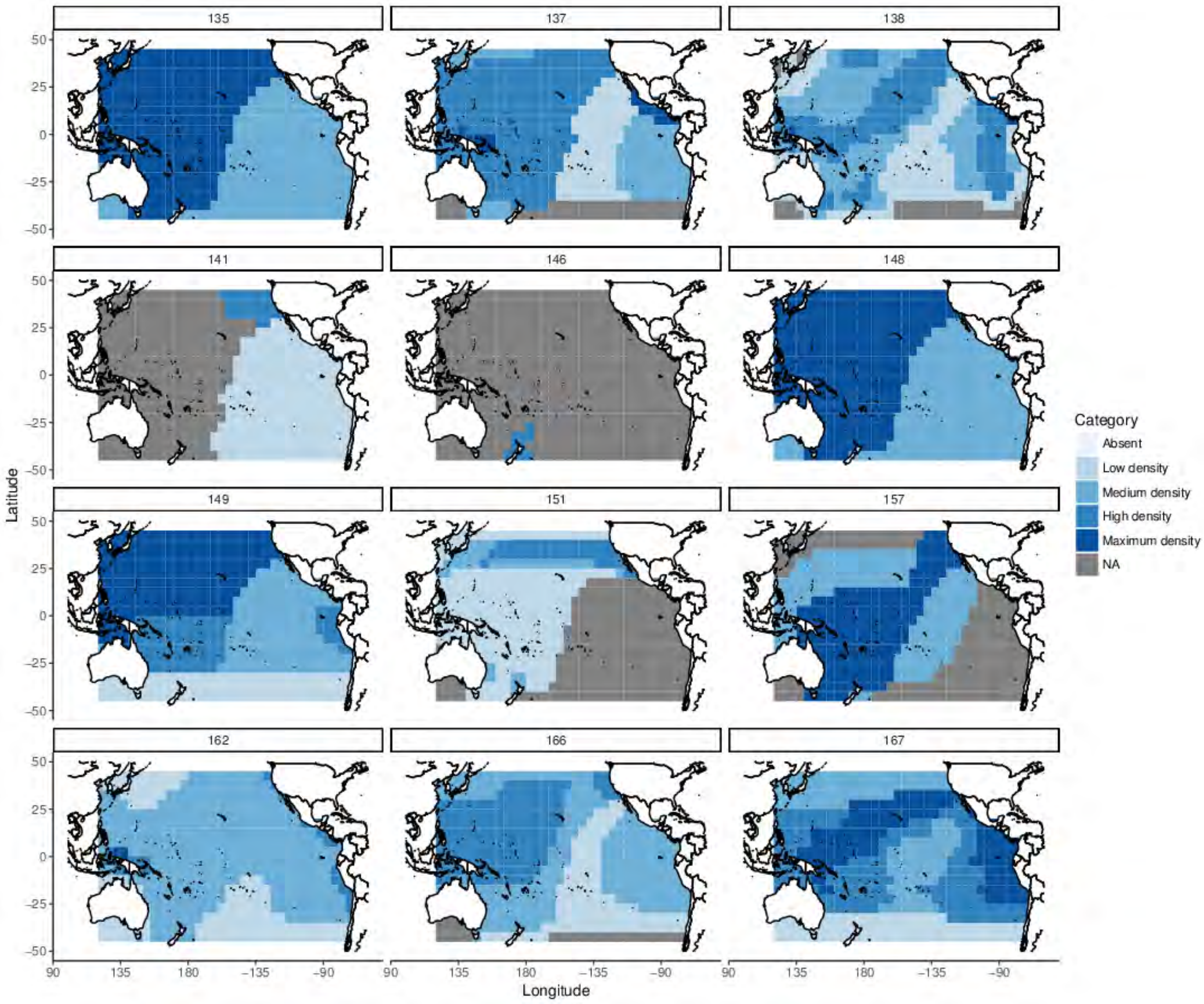

Figure C-8: Relative abundance maps for *Dermochelys coriacea* from the individual participants in the first round of the Delphi survey. Colour shading indicates the abundance categories used in the survey.

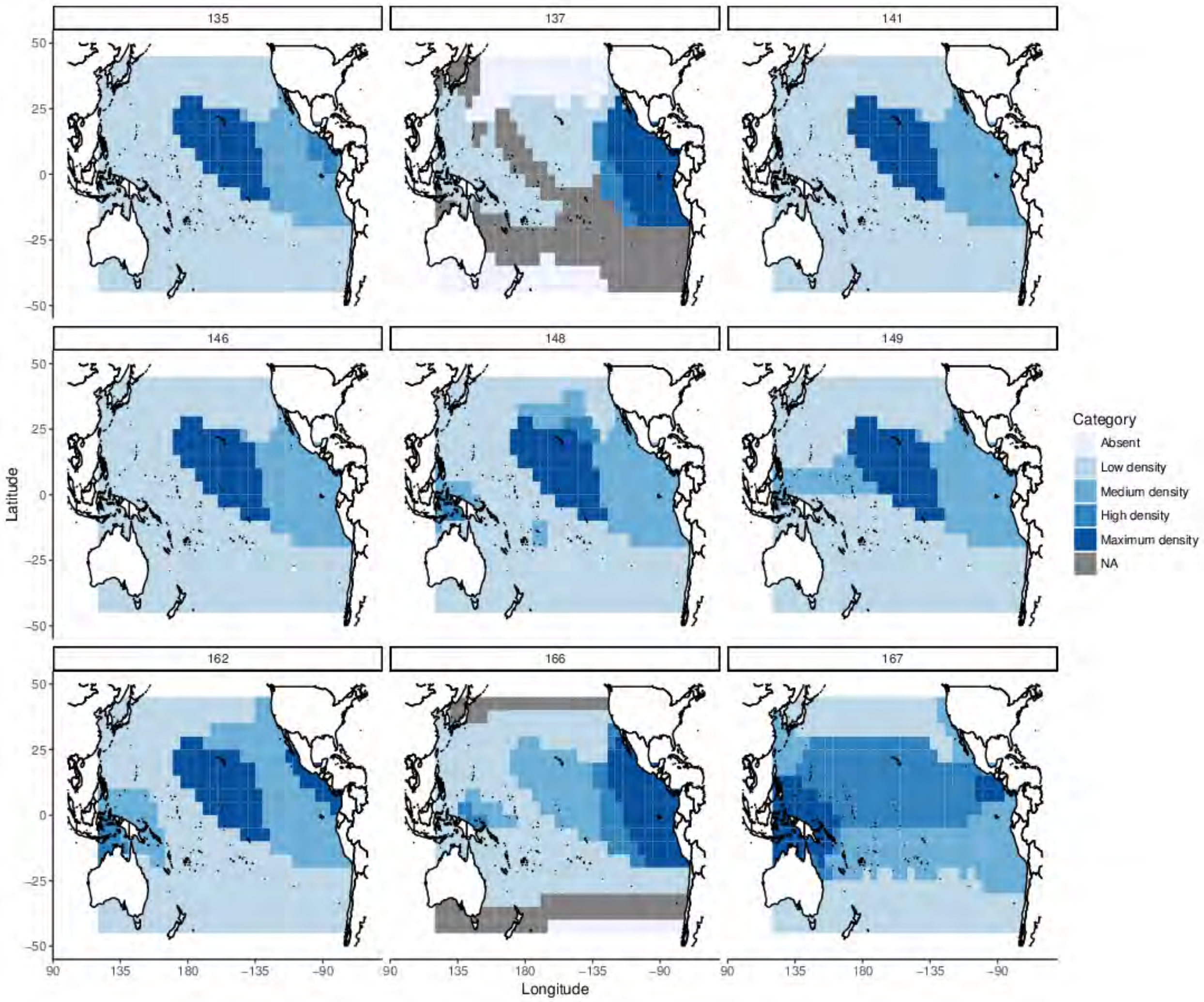

Figure C-9: Relative abundance maps for *Lepidochelys olivacea* from the individual participants in the first round of the Delphi survey. Colour shading indicates the abundance categories used in the survey.

APPENDIX D Respondent maps—Round 2

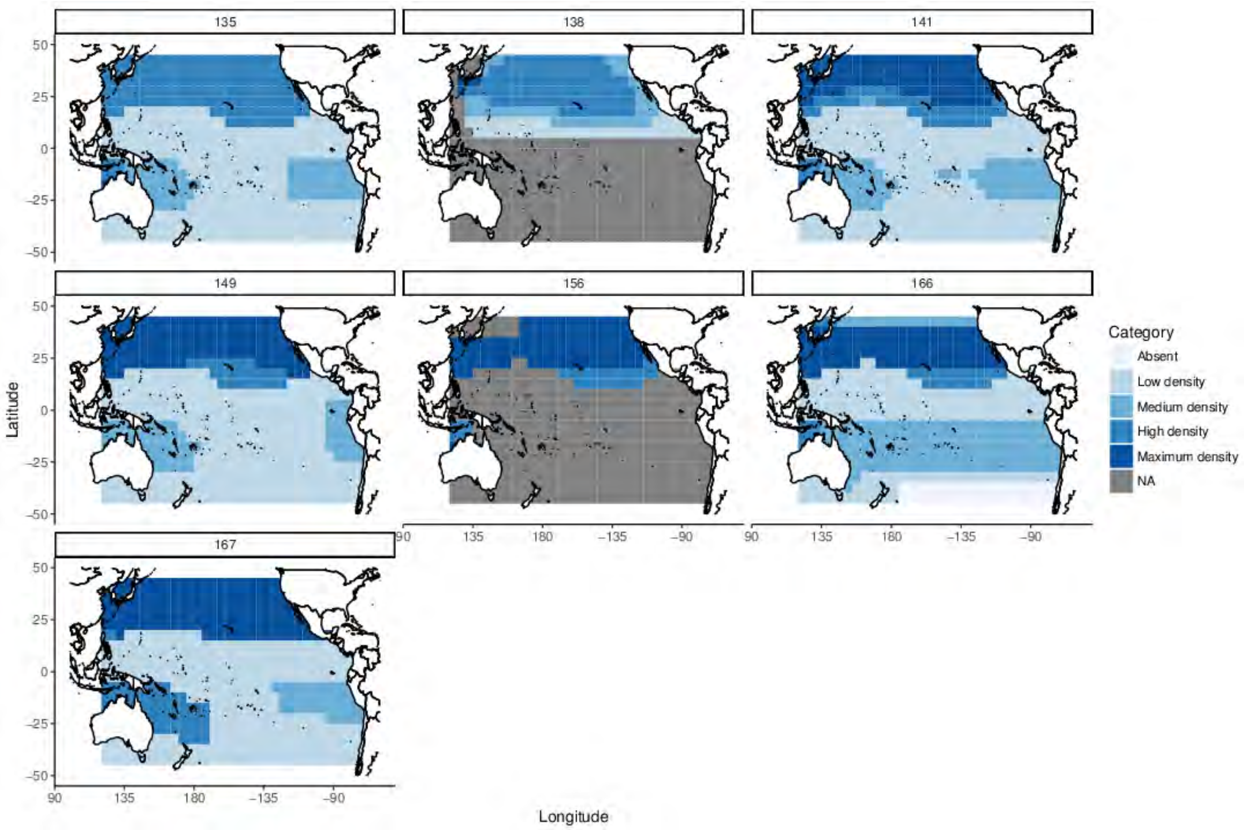

Figure D-10: Relative abundance maps for *Caretta caretta* from the individual participants in the second round of the Delphi survey. Colour shading indicates the abundance categories used in the survey.

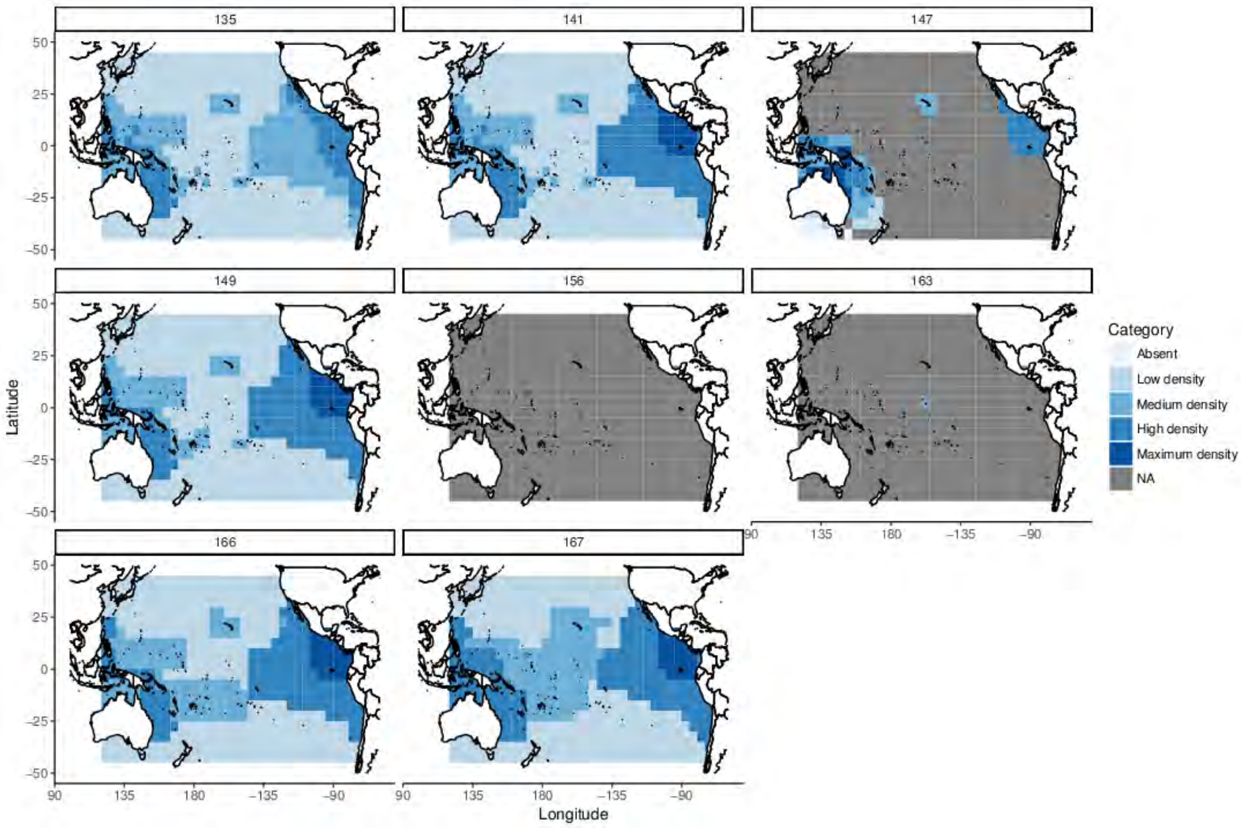

Figure D-11: Relative abundance maps for *Chelonia mydas* from the individual participants in the second round of the Delphi survey. Colour shading indicates the abundance categories used in the survey.

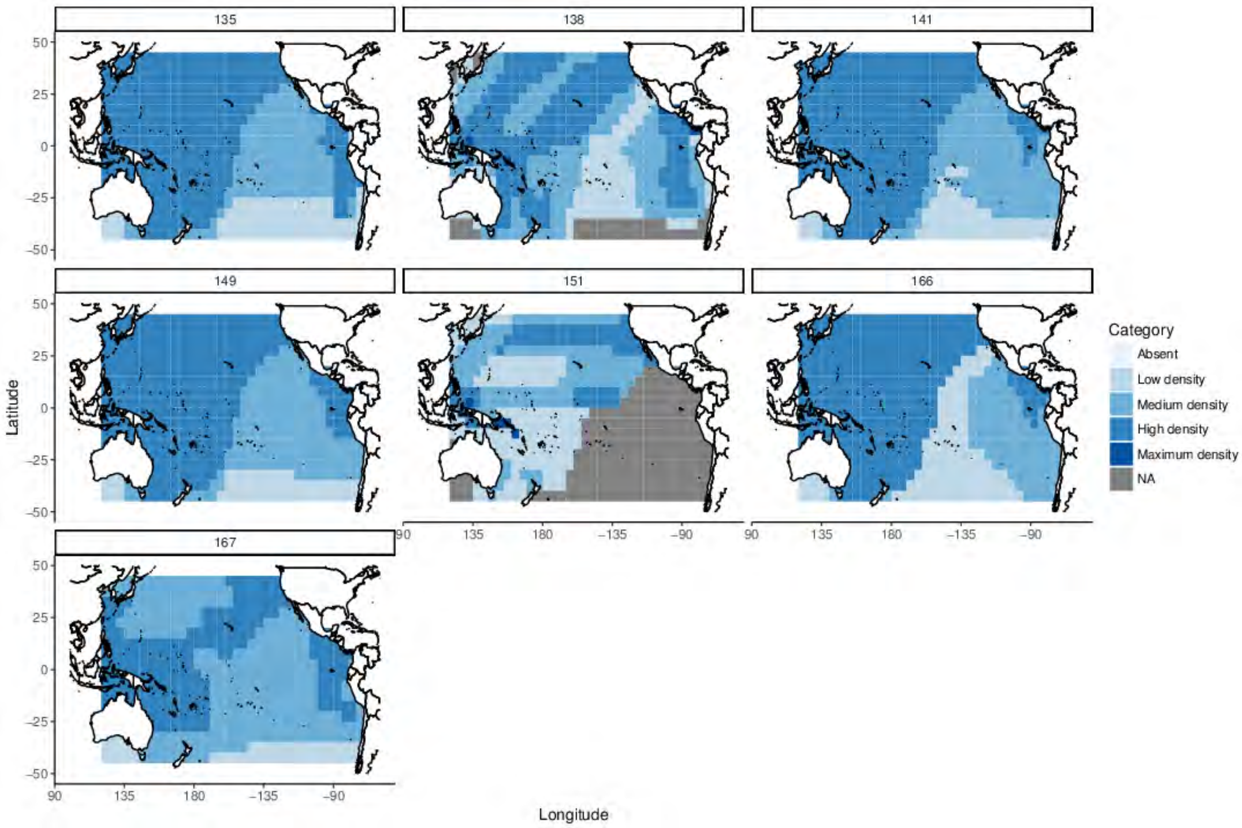

Figure D-12: Relative abundance maps for *Dermochelys coriacea* from the individual participants in the second round of the Delphi survey. Colour shading indicates the abundance categories used in the survey.

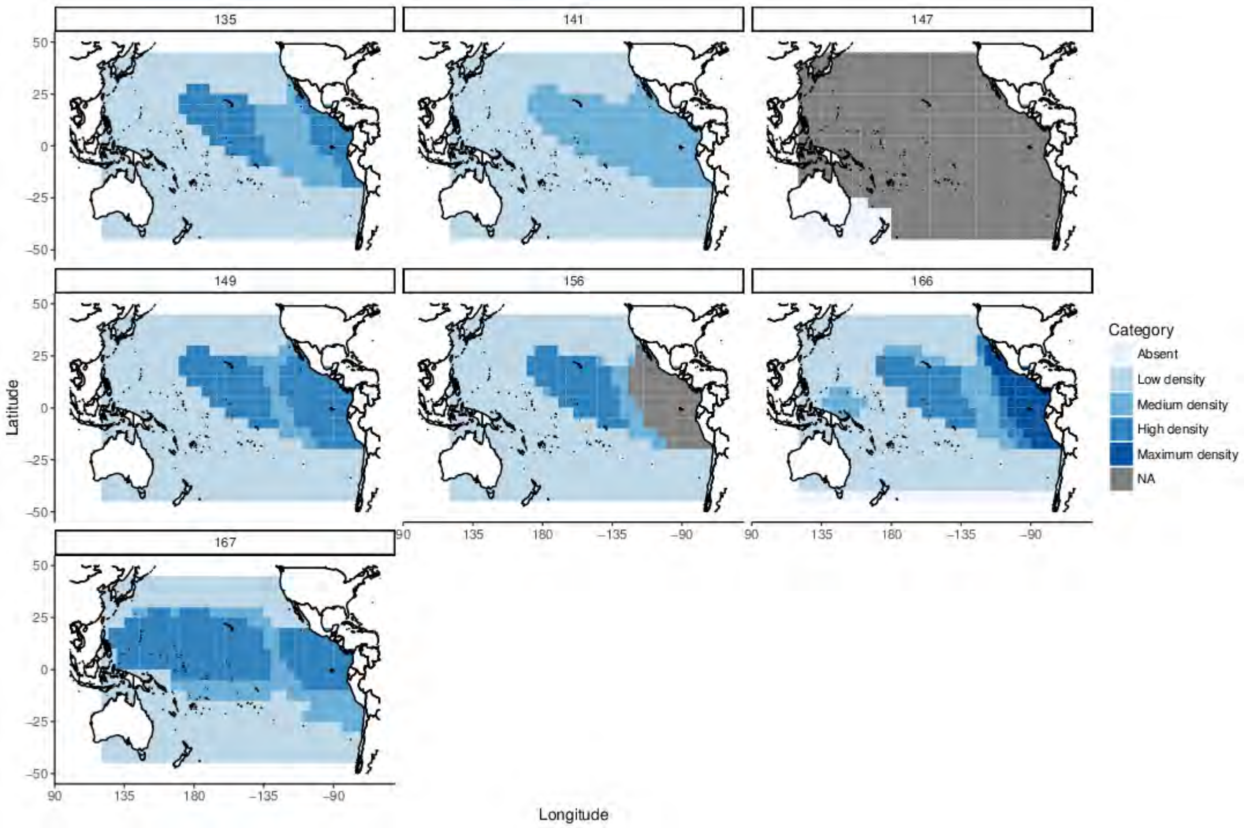

Figure D-13: Relative abundance maps for *Lepidochelys olivacea* from the individual participants in the second round of the Delphi survey. Colour shading indicates the abundance categories used in the survey.